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EXPERIMENTS ON THE STRENGTH OF WROUGHT IRON AND STEEL AT HIGH TEMPERATURES.

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In the following paper an account will be given of experiments made by Dr. Julius Kollmann in 1877–78 on the strength of wrought iron and Bessemer steel at high temperatures, and the results obtained by him will be compared with those obtained in previous investigations of the same subject.

Kollmann's experiments, described by him in a prize essay crowned by the "Verein zur Beförderung des Gewerbfleisses," 1878, were carried on at the iron works of the "Gutehoffnungshütte," at Oberhausen, Rhenish Prussia. Besides numerous tests of the tensile strength of iron and steel at temperatures ranging between 70 and 2000 degrees Fahrenheit, Kollmann's experiments comprised investigations of the resistance of these materials to compression in the process of rolling them into bars and rails, and of various other questions of great practical importance in the manufacture of rolled iron. The present paper will be limited to a consideration of the tensile tests.

Two machines, a larger and a smaller one, were used in making the tensile tests, so that each might check any error in the results obtained

with the other one; both gave, however, closely agreeing results. They were always carefully examined and adjusted before the commencement of each experiment. In the smaller machine the strain was applied to the test piece by means of a hydraulic pump and was measured by weights on a scale beam. In the larger machine the strain was produced by the direct application of weights to a beam, the stretch being taken up by means of gearing, operating upon a screw connected with the lower holder of the test piece.

For the smaller machine the test pieces were made of round and square bars, turned or filed exactly to the following dimensions, viz.: 0·59 inch square, or 0·51 inch diameter in the body for a length of 9 inches, their total length being 11 inches.

For the larger machine the test pieces were cut out of broad flat iron, the strain being always applied in the direction of the fibre. They were made 1·57 inches wide by 0 39 inch thick for a length of 1·38 inches or 2·56 inches, the shorter specimens being used for the higher temperatures, because the stretch of the longer specimens could not have been taken up in the machine.

The test pieces for the smaller machine were heated throughout their whole length in a coke fire. Great care was taken to heat the specimens evenly throughout. A duplicate specimen, having exactly the same shape and dimensions, was heated each time in the same manner to the same degree as nearly as could be judged from photometric measurements by means of colored glasses. This duplicate specimen was used for determining the temperature of the test piece.

The larger test pieces were heated in a forge over a length of 1·38 inches or 2·56 inches, the ends being kept cool by wet coal. A piece of iron having the same dimensions as the heated portion of the test piece was heated at the same time to the same degree, as nearly as could be judged, and was used for determining the temperature of the test piece.

The elongation of the test pieces under a strain was measured by means of an instrument called by Kollmann a "multiplicator." It consisted of two levers connected, like a pair of tongs, by a bolt which served as a common fulcrum. The proportion of the short and long arms of each lever was as one to ten. The ends of the short arms were provided with jaws fitted with set-screws, by means of which the instrument could be attached quickly to the heated test piece after it was secured in the testing machine. One of the long arms carried at

its extreme end an arc on which a scale was marked, and which passed through an opening in the end of the other long arm. When the scale of the arc marked zero, the centres of the jaws of the two short arms were 1·38 inches apart, and any increase of this distance, magnified tenfold, was easily read off on the scale.

The temperature of the test pieces was determined by means of a calorimeter, consisting of a well-insulated copper cylinder containing exactly two litres of water and provided with a cover to prevent loss of water by vaporization. The duplicate test piece, heated as described, was dropped into the calorimeter at the exact moment when the strain was applied to the test-piece. The water was stirred till the temperature of the whole mass and of the test piece was equalized, and the rise of temperature was measured by a carefully tested thermometer. The calorimetric values of the copper cylinder, of the stirrer and of the thermometer had been determined and reduced to an equivalent weight of water. The loss of heat by radiation from the calorimeter was found, by experiment, to be too insignificant to affect sensibly the results obtained. To find the temperature of the test pieces from the rise in temperature of the calorimeter a set of tables were used, which were published in the "Zeitschrift Deutscher Ingenieure," 1875. These tables are based on the following formula for the mean specific heat, C_m, of wrought iron between the temperatures T and t in degrees of the centigrade thermometer, viz.:

$$C_m = 0{\cdot}105907 + 0{\cdot}00003269[T+t] + 0{\cdot}00000001108[T^2+t^2+(T+t)^2]$$

The temperature of the test piece at the commencement of the experiment being thus found, it became necessary to determine how much it cooled off during the experiment. For this purpose numerous experiments were made with the two forms of specimens used in the testing machines. Their initial temperature and final temperature after exposure to the air for a known length of time were measured; the results thus obtained being plotted by laying down the lengths of the time of exposure as abscissæ and the corresponding temperatures as ordinates, a curve was obtained for each of the two forms of specimens, representing the law of cooling on exposure to the air. From these curves the final and mean temperatures of the specimens during the tests were deduced. In order to verify the results thus obtained, the final temperature was directly determined in a number of cases by dropping one of the broken parts of the test piece into the calorimeter.

The mean temperatures found in the above described manner were entered as the temperatures at which rupture took place. The rapid fall of the limit of elasticity and the great reduction of the cross area of the test pieces at high temperatures made it necessary to reduce the differences between the initial and final temperatures as much as possible, and for this reason the tests were made as rapidly as possible: the average duration of each test was but a little more than half a minute.

No allowance was made for any difference in the specific heats of wrought iron and Bessemer steel; the resulting errors in the determinations of temperatures, however, could be but trifling.

Three kinds of iron were tested, viz.: Fibrous wrought iron, fine-grained wrought iron, and Bessemer steel. All the test pieces were taken from the ordinary stock manufactured at the works of the "Gutehoffnungshütte," and not from specially selected material.

A chemical analysis of the specimens gave the following mean results, viz.:

	Fibrous Wrought iron.	Fine-grained Wrought iron.	Bessemer steel.
C,	0·10	0·12	0·23
Si,	0·09	0·11	0·30
P,	0·34	0·20	0·09
S,	0·03	trace	0·05
Mn,	0·07	0·14	0·86
Cu,	0·07	0·06	0·07
Fe,	99·30	99·36	98·40
	100·00	99·99	100·00
Specific gravity,	7·62	7·69	7·84

The fracture of the *fibrous wrought iron* exhibited, as indicated by the name, a long fibre, but with traces of a coarse granular structure. The fracture of the *fine-grained iron* was rather fibrous than granular in appearance in consequence of the great reduction of the bars in the rolls. The *Bessemer steel* had a very even texture and a rather light shade of color.

The square and round iron bars for the small test pieces were rolled from single-piled hammered blooms. The broad flat bars for the large test pieces were rolled from double-piled hammered blooms. The steel bars were twice heated in rolling.

A number of tests made at ordinary temperatures with both machines gave closely agreeing results, showing that the materials were of a uniform quality. Each of these tests lasted from 5 to 14 minutes. The mean results of these experiments were as follows, viz.:

	Fibrous Wrought Iron.	Fine-grained Iron.	Bessemer Steel.
Modulus of rupture, in lbs per sq. in.,	52464	56892	84826
Limit of elasticity, " "	38280	39113	55029
Elongation after rupture, per cent,	17·5	20·	14·5
Contraction of cross-section, per cent.,	20·2	23·77	22·2

Kollmann gives tables showing the results of experiments on the tensile strength of these materials at high temperatures, comprising 52 tests of fibrous wrought iron, 38 tests of fine-grained iron, and 37 tests of Bessemer steel, between the temperatures of 68 degrees and 1976 degrees Fahrenheit. He also gives tables showing the mean values of the modulus of rupture for each material, expressed in per centum of the modulus of rupture at ordinary atmospheric temperature, for each increase of 50 degrees centigrade in temperature from 0 to 1100 degrees centigrade, and graphical representations of these mean values.

	Kollmann's Experiments.			Franklin Institute Experiments.
Temperature in deg. Fahr.	Fibrous Wrought Iron.	Fine-grained Iron.	Bessemer Steel.	Wrought Iron Boiler Plates and Bars.
0	100·	100·	100·	96·
100	100·	100·	100·	102·
200	100·	100	100·	105·
300	97·	100·	100·	106·
400	95·5	100·	100·	106·
500	92·5	98·5	98·5	104·
600	88·5	95·5	92·	99·5
700	81·5	90·	68·	92·5
800	67·5	77·5	44·	75·5
900	44·5	51·5	36·5	53·5
1000	26·	36·	31·	36·
1100	20·	30·5	26·5	
1200	18·	28·	22·	
1300	16·5	23·	18·	
1400	13·5	19·	15·	
1050	10·	15·5	12·	
1600	7·	12·5	10·	
1700	5·5	10·5	8·5	
1800	4·5	8·5	7·5	
1900	3·5	7·	6·5	
2000	3·5	5·	5·	

The diagrams on the plate accompanying the present paper represent these mean values; the temperatures in degrees Fahrenheit being laid down as abscissæ, and the corresponding relative mean values of the modulus of rupture being represented by ordinates. In the above table the *second*, *third* and *fourth* columns contain the heights of these ordinates corresponding to the temperatures given in the *first* column, or, in other words, the relative mean values of the modulus of rupture in Kollmann's experiments.

Column *five* of the foregoing table contains the results of experiments carried on by a committee of the Franklin Institute in the years 1832–36, corrected as will be described further on. The same are represented graphically on the plate accompanying this paper, where the results of experiments conducted by Fairbairn, Styffe, and the British Admiralty are likewise plotted.

Comparing the plotted results of these experiments we observe the following facts, viz.:

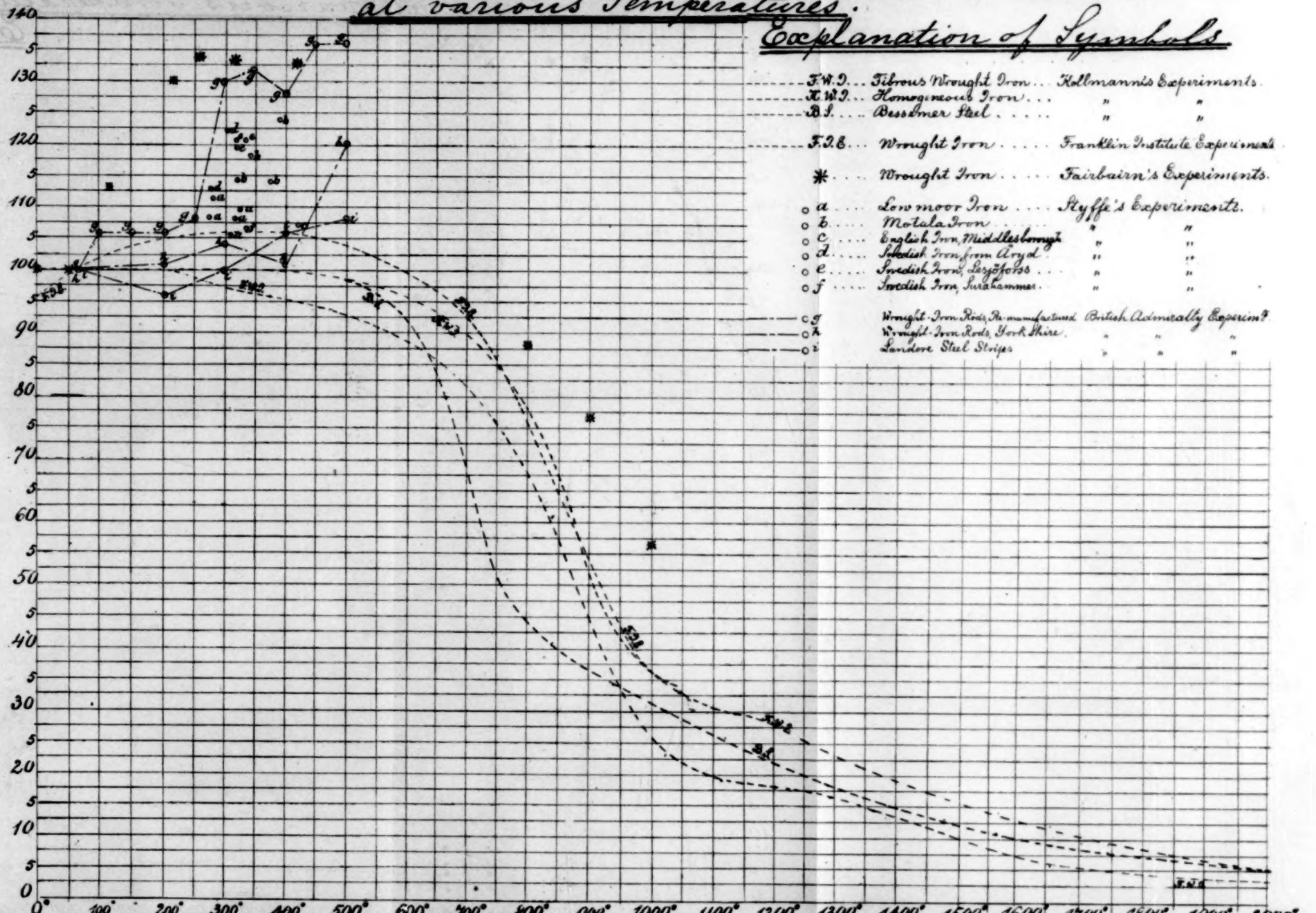
1. In Kollmann's experiments the ultimate tensile strength remained unchanged till, in the case of fibrous wrought iron, a temperature of 200 degrees Fahrenheit, and in the case of fine-grained iron and steel a temperature of 400 degrees Fahrenheit was reached; and after these limits of temperature were passed, the ultimate tensile strength diminished rapidly. On the contrary, all the other experiments, with but a single exception, show a decided increase of tensile strength at temperatures higher than the ordinary atmospheric temperatures; this increase of strength differs greatly in quantity with different materials, and is frequently irregular, but it generally attains its highest value at temperatures lying between 400 and 500 degrees Fahrenheit.

2. At higher temperatures the ultimate tensile strength diminishes in a rapidly increasing ratio till, in the case of Bessemer steel, a temperature of about 775 degrees Fahrenheit, and in the case of wrought iron, a temperature of about 1000 degrees Fahrenheit is reached, when the decrease of strength continues in a greatly diminished ratio, which soon becomes approximately uniform and continues thus as far as experiments have been carried.

The curves representing this decrease of strength of different materials with increase of temperature, though diverging widely at many points, exhibit remarkable similarities in their general features.

It is to be remarked that Kollmann himself attaches the most importance to the results of his experiments at temperatures exceeding

Diagrams representing the Strength of Wrought-Iron and Steel at various Temperatures.


Explanation of Symbols
F.W.I. ... Fibrous Wrought Iron ... Kollmann's Experiments
H.W.I. ... Homogeneous Iron ... " "
B.S. ... Bessemer Steel ... " "
F.I.E. ... Wrought Iron ... Franklin Institute Experiments
* ... Wrought Iron ... Fairbairn's Experiments.
a ... Low moor Iron ... Styffe's Experiments.
b ... Motala Iron ... " "
c ... English Iron, Middlesbrough " "
d ... Swedish Iron, from Arvid " "
e ... Swedish Iron, Lerjöfors " "
f ... Swedish Iron, Surahammer " "
g Wrought-Iron Rods, Re-manufactured British Admiralty Experim?
h Wrought-Iron Rods, York Shire " " "
i Landore Steel Stripes " " "
140 130 120 110 100 90 80 70 60 50 40 30 20 10 0
0° 100° 200° 300° 400° 500° 600° 700° 800° 900° 1000° 1100° 1200° 1300° 1400° 1500° 1600° 1700° 1800° 1900° 2000°

570 degrees Fahrenheit. The tests made below that temperature were few in number; but as they gave results showing a certain regularity, he considered them sufficiently trustworthy to use them in laying down his curves.

A similar statement is made in the report of the committee of the Franklin Institute on the "Strength of Materials employed in the Construction of Steam Boilers," viz., that the tests between the temperatures of zero and 520 degrees Fahrenheit were not sufficiently numerous to determine exactly the shape of the portion of the curve corresponding to those temperatures. These experiments will be discussed more particularly further on; at present we will only remark that in these experiments the increase of strength at temperatures between 400 and 580 degrees Fahrenheit over the strength at ordinary atmospheric temperatures was so marked that it was used as the basis for a mathematical expression of the law according to which the decrease of strength at higher temperatures apparently took place.

Styffe's experiments were made with round and square bars of iron and steel, having a diameter of about one-half inch. The steel bars contained from 0·33 to 1·14 per cent. carbon. The test pieces were immersed in a bath, the temperature of which was measured by thermometers. Tests were made at low temperatures as well as at high temperatures, viz., ranging from 40 degrees Fahrenheit *below* zero to 412 degrees Fahrenheit *above* zero. The increase of strength with increase of temperature varied greatly not only for different materials, but in different bars of the same brand and of the same chemical composition as far as ascertained. As each individual bar furnished only a few test pieces, we cannot determine the *rate* at which the increase of strength took place in these experiments. In plotting the relative strength at high temperatures the mean strength of all the bars of the same brand at ordinary atmospheric temperature has been taken as unity.

Styffe sums up the results of these experiments in the following words, viz.: "From these experiments on tension at widely different temperatures we have thus found:

"1. That the absolute strength of iron and steel is not diminished by cold, but that, even at the lowest temperature which ever occurs in Sweden, it is at least as great as at the ordinary temperature (about 60° Fahr.)

"2. That at temperatures between 212° and 392° Fahr. the abso-

lute strength of steel is nearly the same as at the ordinary temperature; but in soft iron it is always greater."

Fairbairn's experiments were made with 14 specimens, all cut from the same bar of English rivet iron, $\frac{7}{8}$ inch in diameter. The results exhibit considerable regularity. The specimens were immersed during the tests in a bath, the temperature of which was measured by a thermometer. The mean values of the results for certain ranges of temperature have been plotted in the plate. At ordinary atmospheric temperature the strength of the test pieces was 63,000 pounds per square inch.

One specimen, cut from the same bar, was raised to a "red heat visible in daylight," but the temperature was not determined more accurately. In plotting the result of this experiment the temperature has been assumed to have been about 1000 degrees Fahrenheit.

Fairbairn has made another set of experiments with "Staffordshire" boiler-plates at temperatures ranging between zero and 395 degrees Fahrenheit. But owing to the want of uniformity in the quality of these plates, no law of increase or decrease of strength due to changes in temperature can be deduced from these experiments, and Fairbairn himself concluded that between 0 and 400 degrees Fahrenheit the strength of Staffordshire boiler-plates might be regarded as uniform. In one case a plate was heated until it became "perceptibly luminous in the shade" (or to "a scarcely perceptible red heat," as it is called in another place), and in another case a plate was raised to a "dull red heat just perceptible in daylight." No attempt was made to determine the temperatures of these plates more accurately. The results of these two experiments have been plotted, but the values have to be regarded simply as rough approximations.

The experiments by the British Admiralty, the results of which are plotted in the plate, were made in 1877 at Portsmouth dockyard. A somewhat meagre account of them is given in the "Engineer" of October 5, 1877. The strength of the test pieces at ordinary atmospheric temperature was as follows, viz.:

Remanufactured wrought iron rods, 0·74 inch diameter = 58,400 pounds per square inch.

Yorkshire wrought iron rods, 0·70 inch diameter = 59,200 pounds per square inch.

Landore steel strips, 0·74 inch by 0·49 inch = 76,900 pounds per square inch.

That the strength of wrought iron plates and bars increases with an increase of temperature up to about 500 degrees Fahrenheit, and that the amount and rate of this increase of strength with temperature varies greatly, not only for different brands, but for different specimens of the same brand, is a well-established fact; but it must be confessed that a satisfactory explanation of this peculiar behavior of wrought iron cannot be derived from the above-described experiments.

It is well known that the resistance of iron to strains at different temperatures varies according to its chemical composition; it is only necessary to allude to the phenomena of *cold-shortness* and *red-shortness* produced by the presence of certain quantities of phosphorus, sulphur and other ingredients. When the quantity of carbon combined with iron exceeds a certain limit, an increase of temperature is not accompanied by an increase of strength. In the British Admiralty's experiments cast iron was stronger at ordinary atmospheric temperature than at higher temperatures. In Styffe's experiments, different kinds of steel containing from 0·33 to 1·14 per cent. of carbon exhibited, on the whole, no increase of strength at higher temperatures. When the amount of carbon in wrought iron is 0·21 per cent. or less, its influence on the increased tensile strength of the test pieces at higher temperatures is not apparent in these experiments; nor can a connection be traced between the amount of phosphorus present in the iron and the strength of the latter at higher temperatures. The amounts of these two substances in the specimens of wrought iron tested by Styffe were as follows, viz.:

	Carbon.	Phosphorus.
Lowmoor iron,	0·21 per cent.	0·068 per cent.
Motala iron,	0·20 per cent.	0·020 per cent.
Middlesborough iron,	0·07 per cent.	0·25 per cent.
Aryd iron,	0·07 —0·18 per cent.	0·26 per cent.

It seems probable that the property of iron under consideration is dependent directly on the internal structure of the metal, and on its chemical composition mainly in so far as it determines to a certain extent the aggregation of the particles of the metal, viz., whether it be fibrous, granular or crystalline. To understand clearly the structural changes undergone by iron in the process of manufacture we must know the amount of reduction it has received, or the proportion of cross-section of the pile or bloom to that of the finished article, besides the manner in which, and the temperature at which, the reduction has

taken place. That these conditions influence greatly the ultimate strength as well as the elastic limit and the ductility of iron is well known; likewise, that by the process of rolling various permanent strains of greater or less magnitude are produced in every bar and plate, in consequence of the different amount of work expended upon, and compression experienced by, different parts of the bar or plate at the same cross-section. In steel bars and plates these internal strains are often so great that only a small additional strain is needed to produce fracture; but these internal strains may generally be relieved by annealing, as the peculiar granular or crystalline structure of steel seems to favor a re-arrangement of its particles at moderately high temperatures. In the case of wrought iron annealing by heating and gradual cooling produces a less marked effect in this respect. Considering wrought iron plates and bars as consisting of an aggregation of fibres, we may suppose that these fibres experience at ordinary temperatures an unequal amount of internal tension, which is relieved to a certain extent as the body expands and the fibres change their relative position in consequence of a rise of temperature; but that, with a fall of temperature, the fibres return to their original position and condition; and that thus only during the continuance of higher temperatures the internal strains are diminished and external strains are evenly distributed among the several fibres. On this hypothesis an increase of temperature will produce an increase of strength till the weakening effect of the repulsive action of heat on the molecules of the body counterbalances the effect of a diminution of internal strains and a more equal distribution of the strains produced by the load among the fibres. On the whole, the influence of temperature will probably be the more marked, the more fibrous the structure of the iron and the more work it has received at low temperatures. Round and square bars will probably show the influence of temperature more than flat bars and plates under otherwise equal conditions.

While these conclusions are consistent with the results of the above-described experiments, they cannot be considered as definitely proven; and they are given here mainly to indicate in what direction further inquiries into this subject may be made to advantage. The fact that Kollmann, contrary to all other experience, found no increase of strength at higher temperatures does not necessarily indicate that his observations were incorrect or his methods insufficient; but it may have been due to the character of the metal tested by him. It is

stated that the iron from which he took his test specimens entered the rolls at a temperature of about 2100 degrees Fahrenheit, and left them in the finished state at a temperature of about 1700 degrees Fahrenheit.

In this connection it is also interesting to compare the results obtained by Wertheim, Pisati and others with iron and steel wire. We select the following example from Pisati's experiments: The wire had been annealed at a dark-red heat; the strength decreased as the temperature rose from 57 to 122 degrees Fahrenheit; then it rose up to 192 degrees Fahrenheit, and fell again rapidly to 248 degrees, after which it remained constant up to 392 degrees, and after falling slowly to 455 degrees it rose again suddenly and then fell slowly; but at 572 degrees Fahrenheit the strength was still greater than at 57 degrees Fahrenheit. (See "Poggendorf's Annalen," vol. i, 1877.)

We have only a single series of experiments to compare with Kollmann's tests at temperatures exceeding 500 degrees Fahrenheit, viz., those made by a committee of the Franklin Institute in 1832–36. For the details of these experiments we have to refer the reader to the report of the committee. The manner of preparing the test pieces, and the method of computing mean values from the results of these early experiments are, no doubt, open to criticism; but the curve representing the rate of decrease of strength of wrought iron at high temperatures, given in the original report, is so strikingly similar to the curves representing the results of Kollmann's experiments, that we are compelled to believe that the general law of the decrease of strength of iron at high temperatures is correctly represented by these curves. The original curve representing the results of the Franklin Institute experiments gives, however, a much smaller decrease of strength at high temperatures than that found by Kollmann's experiments; but a closer investigation shows that this discrepancy did not exist between the *actual* results of these two sets of experiments, as will be seen from the following, viz.:

In the report of the Franklin Institute experiments the strength at high temperatures is not compared directly with the strength at ordinary atmospheric temperature, but with a standard of *maximum tenacity*, which is assumed to be 15·17 per cent. greater than the tenacity of the specimens at ordinary atmospheric temperature, for this was found to be the mean of the highest increase of tenacity corresponding to an increase of temperature above atmospheric temperature, deduced from a large number of tests.

In laying down the corrected curve of the Franklin Institute experiments in this paper, the tenacity of iron at ordinary atmospheric temperature has been taken as unity.

Further, in the Franklin Institute experiments the test pieces were kept immersed in a hot bath, and when the temperature of the bath was too high to be accurately measured with a mercurial thermometer, it was determined in the following manner, viz.: A piece of iron of a known weight, which had been kept immersed in this hot bath, was plunged into a vessel containing a known weight of water of a known temperature; the weight of water vaporized in this manner was used for computing the temperature of the piece of iron corresponding to the temperature of the bath and of the test piece; but in making this computation the latent heat of steam of atmospheric pressure was assumed to be 1037 degrees Fahrenheit, instead of 966 degrees Fahrenheit, as determined subsequently by Regnault; and the specific heat of iron was taken to be 0·11336 and uniform for all temperatures, while according to the formula by which Kollmann's temperatures were determined the specific heat of wrought iron is much greater at high temperatures. In consequence of these differences the temperatures given in the report of the committee of the Franklin Institute are much greater than those calculated by Kollmann's formula. In laying down the curve in the present paper the temperatures have been corrected by using the constants used in Kollmann's computations.

For temperatures above 500 degrees Fahrenheit the corrected curve of the Franklin Institute experiments agrees to a remarkable degree with Kollmann's curves, especially with the curve for fine-grained iron, which it intersects twice and to which it is tangent at the point corresponding to a temperature of 1000 degrees Fahrenheit. A noteworthy fact is that at the point corresponding to this same temperature both curves representing Kollmann's tests of wrought iron as well as the Franklin Institute curve change suddenly in direction and in a similar manner. The Bessemer steel curve exhibits a much more rapid decrease of strength than the wrought iron curves, and its change of direction takes place at a temperature of about 775 degrees Fahrenheit.

It is a very interesting fact that the range of temperatures (viz., from 500 to 1000 degrees Fahrenheit) for which these curves exhibit such a remarkable rate of decrease of tenacity, coincides almost exactly with that at which wrought iron and mild steel possess a

remarkable weakness with respect to percussive forces, as was first announced by Daniel Adamson in a paper read before the Iron and Steel Institute, from which we quote the following:

"*Nearly all ordinary bar and boiler iron and mild steels will endure considerable percussive force when cold, and up to 450 degrees Fahrenheit, after which, as the heat is increased, probably to near 700 degrees Fahrenheit, they are all more or less treacherous and liable to break up suddenly by percussive action.*" (See "Journal of the Iron and Steel Institute," No. 2, 1878, p. 396.)

At higher temperatures these metals are free from this singular weakness. Adamson's observations have been verified by later experiments made by the British Admiralty.

Unfortunately we possess but very scant information regarding the effect of high temperature on the ductility and the limit of elasticity of wrought iron and steel.

Styffe found from his experiments "that neither in steel nor in iron is the *extensibility* less in severe cold than at the ordinary temperature; but that from 266 to 320 degrees Fahrenheit it is generally diminished, not to any great extent, indeed, in steel, but considerably in iron," and "that the *limit of elasticity* in both steel and iron lies higher in severe cold; but that at about 284 degrees Fahrenheit it is lower, at least in iron, than at the ordinary temperature."

It must be remembered that in Styffe's experiments the steels contained from 0·33 to 1·14 per cent. of carbon.

The following table exhibits the ductility of the wrought iron and steel specimens tested by the British Admiralty at Portsmouth dockyard in 1877. The second, third and fourth columns contain the elongation of the specimens after rupture, expressed in per cent. of the original length of 10 inches.

Temperature in degrees Fahr.	Wrought Iron. Remanufactured Rods.	Wrought Iron. Yorkshire Rods.	Landore Steel Strips.
Ordinary temperature,	22·	25·	26·
100	18·75	24·25	
150	15·		
200	15·	17·25	22·5
250	15·		
300	15·5	7·5	11·25
350	12·5		
400	12·	15·	10·25
450	15·		
500	20·	13·75	10·

The manner in which Kollmann's experiments were made did not permit an accurate determination of the ductility of iron at high temperatures. The general conclusion drawn by him from the results of his experiments, which are, however, very irregular, is that the elongation increases with a rise of temperature up to 850 degrees Fahrenheit for wrought iron, and even higher for Bessemer steel. He promises to give further investigations of this matter at a future day.

Kollmann's method of heating his test pieces in a furnace and allowing them to cool off during the process of testing was obviously defective, and the results obtained by him can only be regarded as rough approximations. Although the tests did not last more than half a minute, the specimens cooled off fully 100 degrees Fahrenheit at the higher temperatures; and even a difference of 50 degrees Fahrenheit would affect materially the tenacity of iron between the temperatures of 500 and 1000 degrees Fahrenheit. The great rapidity with which the tests had to be carried on was another source of inaccuracies. In order to observe carefully and measure accurately the effect of heat upon the tenacity, ductility and elasticity of iron, the specimens must be maintained at a uniform temperature by keeping them immersed in a bath. This can be readily done as long as the temperature does not exceed 1000 degrees Fahrenheit. Beyond that temperature Kollmann's method of heating the test pieces is probably the least troublesome and sufficiently accurate.

The importance of making further investigations of the subject discussed in this paper need not be dwelt upon. We wish, however, to call the special attention of manufacturers of rolled iron and steel plates and bars to the immediate advantages which they may expect to reap from similar investigations. Carefully conducted and intelligently analyzed experiments relating to the behavior of iron at high temperatures will enable them to estimate correctly the relative value of various methods of treating the metal in the process of rolling, and may also throw some light on the obscure causes producing those internal strains which often render rolled iron of very uncertain value with regard to strength, ductility and elasticity.

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NOTE RELATING TO THE PROPER METHOD OF EXPANSION OF STEAM AND REGULATION OF THE ENGINE.

By PROF. R. H. THURSTON.

Read before the American Society of Mechanical Engineers, Altoona Meeting, August, 1881.

It has long been well known, to every engineer experienced in the construction and management of the steam engine, that when working under known conditions and at a given pressure of steam, there is a certain ratio of expansion which gives highest efficiency, *i. e.*, least expenditure of fuel in proportion to work done. It has also been long known that the most economical ratio of expansion, all things considered, when studied from the commercial standpoint, is to be determined not simply by studying those conditions which affect the efficiency of the engine, but by consideration of all the elements of cost of steam power, including first cost, interest on capital expended, wear and tear and running expenses for fuel supply and management.

In the design of an engine it thus becomes necessary, if the designer would consult the best interests of the purchaser of the engine, first to determine as best he can what is likely to be the cost of each series of engines of the style proposed and of graded sizes; next must be determined the cost of power in weight of steam used in each of these engines at various pressures and ratios of expansion; finally, by comparison, he must select that engine which at the least ratio of expansion, all things considered, will give the required power.

When the steam pressure and the cost of power in steam consumption are known, it becomes possible to determine the best point of cut-off. But no engineer has yet been able to say with certainty what, in any given case, will be the ratio of expansion giving highest efficiency, or what, at any given rate, will be the probable expenditure of steam or fuel. The writer has endeavored, in an earlier paper,* to show what are the causes of this uncertainty, what determines the most efficient adjustment of expansion, and what, on the whole, have, in his judgment, proved to be the ratios of expansion giving maximum effi-

* "On the Ratio of Expansion at Maximum Efficiency," Trans. Am. Soc. Mech. Engrs., 1881; Journal Frank. Inst., May, 1881.

ciency, and, finally, what efficiency may probably be anticipated in cost of steam and of fuel in good engines, adjusted for maximum efficiency.

When these points are settled the engineer may, by a proper use of the factors, ascertained as above indicated, determine what is the best ratio of expansion to adopt, or rather what is the best size of engine for the case in hand, and what the best type of valve gear and regulating mechanism. The size and kind of engines is therefore determinable from a knowledge of conditions, which are partly physical and incidental to construction, and partly commercial.

The solution of this second and broader problem may be effected either by a tentative process of trial and repeated estimation, or by an approximate, and for some cases—*e. g.*, where cylinder condensation is reduced to a minimum, as in efficiently jacketed or in fast-moving engines, or at low rates of expansion—nearly exact method, first indicated, so far as the writer is aware, by Professor Rankine,* who applies to the case one of those beautiful graphical constructions in the devising of which he was so ingenious and successful.

This method has been studied and has been applied to representative examples in recent practice in steam engineering by Messrs. Wolff & Denton,† who have shown that the commercially profitable grades of expansion are ordinarily restricted to a very narrow range, and always somewhat less than the ratio for maximum efficiency.

Having, then, fixed upon the size of engine and ratio of expansion, it is evident that this ratio of expansion should generally be kept invariable, so long as the steam pressure remains unchanged.

The usual changeable condition with a given engine is the demand for power, and to meet this variation it becomes necessary to adopt some method of regulation. The simplest forms of regulating apparatus usually consist of a "fly-ball" governor set to operate a "throttle-valve" or other kind of regulating valve; the most usual method of regulation with the better class of engines is that adopted by Corliss—the attachment of the governor to the expansion gear in such a manner as to cause a variation of the ratio of expansion, adjusting the point of cut-off to the demand for power. This latter is the most sensitive regulating mechanism yet devised, and where the variation

* Phil. Magazine; Trans. R. S. E.; Theory and Practice of Shipbuilding; Miscellaneous Papers.

† Trans. Am. Soc. Mech. Engr's, 1881; The American Engineer, 1881.

is small is very effective even at low speeds. The writer has counted the revolutions of a Corliss engine making about sixty revolutions per minute, with steam at 90 lbs. by gauge (7 atmospheres), and found a variation of but two revolutions per minute when the whole load was thrown off or on, the minimum being about 35 horse-power (driving shafting) and the maximum about 150.

Since, however, the proper ratio of expansion for the engine when once installed is determined mainly by the steam pressure, and since any variation from that point is usually productive of reduction of efficiency, it would seem that the ratio should be fixed at the best proportion for the steam pressure adopted and never changed. This being the case, the question arises, how shall regulation be effected? The adjustment of a throttle-valve by the governor is inadmissible, as it involves variation of the steam pressure in the steam chest and consequently reduced efficiency; the steam and expansion lines must be permanently fixed for all loads.

It becomes at once evident that any allowable system of regulation must now affect the back pressure or the cushion line. To throttle the exhaust by the action of the governor would undoubtedly give a means of regulation, but a costly one; since any increase of back pressure during the exhaust would involve serious increase in the amount of rejected heat and of waste of power.

It then becomes evident that the only admissible plan is the variation of the net power of the engine by an alteration of the compression line. This is done where one very well known and generally used valve gear is adopted—the Stephenson Link Motion. When the link is down the ratio of expansion is determined by the lap and lead, and is usually not higher than $\frac{1}{3}$; as the link is raised this ratio is increased, and with this change of the steam line occurs a simultaneous alteration of the point of release and of closure of the exhaust passages, resulting in increased compression. This double effect gives the indicator diagram a peculiar modification of form, familiar to engineers who have taken cards from the locomotive or the usual type of marine engine. The smoothness of working of such engines when running with high steam and a raised link has probably been observed by all experienced engineers, and it may not have escaped notice that under such conditions the expenditure of steam is often so low as to indicate some source of economy other than simple change in the ratio of expansion.

The writer, at least, when in charge of naval steam machinery during the war of 1861–5, was led to suspect a gain from this distribution of steam, which could only be attributed to what was considered excessive compression.

His attention has recently been called to this matter again by the interesting results of a series of experiments made upon a large engine fitted with variable expansion gear. The valve motion is so arranged as to permit adjustment of compression without change of either steam, expansion or exhaust lines. The results will be reported in a later paper. It is only necessary here to state that a decided gain is found to follow the adjustment of the compression to a far higher ratio than is indicated as best by the simple geometrical conditions usually studied and generally taken as those determining the proper ratio of compression. This beneficial effect of a high ratio of compression has been attributed by the writer to the action of the compressed fluid in heating the passages and the cylinder head and piston, thus checking to a very great extent that initial cylinder condensation which is the greatest source of avoidable waste in nearly all engines.

It may be asserted that the best compression, where no such transfer of heat occurs, is not far from that which makes the ratios of expansion and compression equal, and the engineer will usually set the exhaust valve to close at the point corresponding to maximum expansion. For the reasons just given, however, and as shown by direct experiment, maximum efficiency is obtained with higher ratios of compression, and what would have been considered excessive cushioning gives less loss than equal variation from the point of cut-off giving maximum efficiency. As compression is increased, the area of the indicator diagram decreases and the work developed in the engine becomes less.

It would seem, then, that we have here an admissible method of regulation and one which should be, on the whole, that best fitted to give high efficiency, since any excess of work of compression results simply in the transfer of heat back to the steam side. The steam engine should, therefore, be worked with a fixed cut-off,* so attaching the governor as to determine the point of closing of the exhaust valve—in other words, making the "cut-off" operate on the exhaust

*The writer has devised methods of automatic readjustment of the ratio of expansion when variations occur in the steam pressure, which methods would in the case here taken replace the usual adjustment by the governor.

side, the ratio of compression being determined by the governor—instead of attaching the cut-off mechanism to the steam valves. Properly constructed relief valves will prevent all danger from the influx of water with the steam, an accident which, however, should never occur where provision is made for securing dry steam. With exhaust ports beneath the cylinder, drainage is rarely imperfect.

In slowly moving pumping engines it has sometimes been found beneficial to extend compression until boiler pressure is exceeded, and the writer has indicator diagrams taken from such engines in which the compression line crosses the steam line before the end of the return stroke has been reached. He has, as probably has every engineer who has been accustomed to handle locomotive or marine engines, often set the link motion so as to give such high ratios of expansion and compression as to reduce the card to a comparatively narrow band, without perceiving the slightest evidence of objectionable loss of smoothness of working and with decidedly improved efficiency. It seems to the writer doubtful whether, in practice, objectionable or "excessive" compression ever occurs in such cases, and the advantages of this method of regulation and of securing a lessened variability in the ratio of expansion would appear to be decided and to be obtainable without meeting with serious difficulties.

The plan is probably not entirely a novel one and may have suggested itself to many engineers independently; but no attempt has previously, so far as the writer is aware, been made to determine its advantages in actual work. The writer indicated this as the proper method of adjusting expansion some years ago,* and has since had it presented to him by other engineers with whom the thought was also original.

Where the plan here suggested cannot be adopted conveniently, maximum economy of steam should be obtained by an expansion gear in which, as in locomotive valve gear, increased expansion is accompanied by increased compression, but without that serious throttling along the steam line which usually characterizes the distribution by the link-motion.

The best among existing forms of valve gear should be, if judged from the standpoint here taken, that which—combining a variable expansion with a variable compression—is also capable of prompt and exact adjustment by a sensitive and efficient governor.

* History of the Steam Engine: D. Appleton & Co. (International Series), N. Y., 1878, p. 473, foot note.

The economy to be expected from the suggested change in methods of regulation of the steam engine will evidently be dependent upon the manner of operation of the engine. Where engines have a nearly invariable load, and when they are well adjusted to their work, the advantage would probably be found inappreciable; but in cases in which the engine is much too large for its work or when the demand for power is very irregular, as in rolling mills or in rough weather at sea, and where cylinder condensation occurs to a great extent, the increased efficiency may be found to be very considerable. The gain by decreased internal condensation will, perhaps, often be found to be an item of no small importance.

Hoboken, N. J., June, 1881.

ON THE LAST EXPERIMENT (19TH MARCH, 1881) WITH THE PERKINS MACHINERY OF THE STEAM YACHT "ANTHRACITE."

By Chief-Engineer ISHERWOOD, U. S. Navy.

In the January, February and March numbers of the present year of this journal will be found a description of the Perkins system of steam machinery in the steam yacht *Anthracite*, together with an account of the two experiments which had been made with it to determine its economic efficiency. The first experiment was made in England, with the vessel in free route, by Mr. F. J. Bramwell, an engineering expert employed for that purpose by the "Perkins Engine Company," and the second was made by a Board of Chief-Engineers of the United States Navy with the vessel secured to the dock of the New York Navy Yard.

There being a wide discrepancy between the results of these two experiments, the "Perkins Engine Company," on the return of the *Anthracite* to England, caused Mr. Bramwell to repeat his original experiment; and it is the object of this paper to give the data and results of the repetition—which are substantially the same as those of his original experiment—as a further contribution to a knowledge of what economy may be expected from the employment in a steam engine of steam of exceptionally high pressure used with a correspondingly great measure of expansion.

The three experiments above referred to, being all that ever were made with steam of the excessive pressure employed and so enormously expanded, have a peculiar value on account of their fewness and of their greatly exaggerated conditions of pressure and expansion, nothing remotely approaching either being found in ordinary practice.

Before giving the data and results of the repeated experiment, it is necessary to impress the reader with the fact that the three experiments above referred to, being all made under substantially the same conditions of high pressure and great expansion, have nothing with which they can be properly compared.

The contention of the "Perkins Engine Company" is that the higher the pressure of steam and the more it is expanded, the greater will be the economy. To show this effect, one or many experiments on the same machinery, if all be made under the same conditions, are insufficient. A series is necessary, with varying conditions, beginning with the highest pressure and greatest expansion and gradually reducing both, ending with the least pressure and expansion of ordinary practice, ascertaining experimentally the results with each reduction; thus proving or disproving, as the event may be, whether or not the position of the "Perkins Engine Company" is well- or ill-founded. That Company, however, has not made such experiments; and the two conducted by Mr. Bramwell are incomplete in the non-ascertainment of the weight of feed-water consumed per hour. In the one conducted by the Board of United States Naval Engineers, however, this weight was determined.

As part of the economic effect of an engine, measured by the cost of the power it develops in pounds of coal consumed per hour, is due to the quality of the coal, part to the type and proportions of the boiler, and the remainder to the type and proportions of the engine—including therewith the pressure, quality and expansion of the steam used, it is necessary to separate these factors and ascertain what portion of the whole effect is due to each. Now, in the experiments made by Mr. Bramwell, the finest description of hand-picked Nixon's navigation coal was burned, a coal of exceptional quality for generating steam and of proportionally increased cost; and, manifestly, whatever may be the difference in weight of water vaporized in a boiler by unity of weight of this coal and by others of very considerably inferior quality, should not be attributed to the machinery; so

that Mr. Bramwell's experiments fail at the outset in furnishing data with the Perkins engine for any proper comparison with engines using steam generated by inferior qualities of coal.

Mr. Bramwell's last experiment shows that the steam furnished by the Perkins boiler was not superheated. Now, as that boiler contains 14·7227 square feet of water-heating surface, measured on the interior surface of the tubes, or 19·6033 square feet measured on their exterior surface, and 15·6179 square feet of steam superheating surface, measured on the interior surface of the tubes, or 21·2178 square feet measured on their exterior surface—all per square foot of grate surface—there follows that, practically, this boiler had (14·7227+15·6179=) 30·3406 square feet of water-heating surface, measured on the interior surface of the tubes, or (19·6033+21·2178=) 40·8211 square feet, measured on the exterior surface of the tubes; because, if water had not been on the whole of this surface, the steam must have shown some superheating; and, had the water been on only the normal water-heating surface, the steam would certainly have been excessively superheated with so great a proportion of steam superheating surface to grate surface. Thus the Perkins boiler, though furnishing only saturated steam, had an exceptionally large proportion of water-heating to grate surface; in virtue of which, the pound of coal would vaporize in it a larger quantity of water than in a boiler in which the ratio of the water-heating to the grate surface was the much less proportion employed in ordinary practice. In this connection, too, must be remarked that the rate of combustion in the Perkins boiler, for a full power trial, was less than half the rate of ordinary practice with the coal used; so that less than half the quantity of heat per hour was thrown upon about one-third more heat-absorbing surface, producing, of course, the greater economic vaporization due to these exceptionally favorable conditions.

Before Mr. Bramwell's last experiment was made, the pitch of the *Anthracite's* screw was largely increased, so that with a given weight of steam passed through the engine per hour, the steam pressures in the cylinders would all be higher and the piston speed lower than in his first experiment.

Before the system according to which the *Anthracite's* machinery was designed and is worked can be accepted as experimentally proven to be economically superior to any other in use, the weight of feed-water consumed per hour, as well as the power developed, must be

ascertained for a series of pressures and expansions, the results of all which shall be found to converge in the same direction, showing an increased economy for each increase in the pressure and in the expansion. Until this is done, however, the experiments that have been made are of great interest; the data and results of the last being as follows, excepting that the writer has supplied from other sources an approximate estimate of the weight of feed-water consumed per hour and the deductions drawn therefrom. None of the quantities in the following table are to be found in Mr. Bramwell's report, but the writer has obtained them from the data therein given, which includes a reproduction of all the indicator diagrams taken. In fact, the report itself contains but little more than the observed data of the experiment, leaving the reader to make his own calculations and deductions.

The writer has selected from the data of the report the ten hours of the performance during which the machinery was operated with the fire in full and steady action, supplying a uniform weight of steam of uniform pressure per hour. It is assumed that at the end of these ten hours the fire was in the same condition as regards cleanness and thickness, and that the quantity of water in the boiler and the pressure of the steam were the same as at the beginning, which they undoubtedly were as nearly as could be judged. A set of indicator diagrams were taken every half hour; a set comprising a diagram from the top of the 1st cylinder, a diagram from the bottom of the 2d cylinder and a diagram from the top and bottom of the 3d cylinder. The steam and other pressures and the temperatures were noted half hourly. The machinery worked well and smoothly, with great regularity and entire freedom from hot journals.

The calculations from the data have been made by the writer in exactly the same manner as for the two previous experiments.

Table Containing the Data and Results of the Experiment made in England, by Mr. F. J. Bramwell, on the Machinery of the Steam Yacht "Anthracite," to Determine its Economic Performance.

Total Quantities.

Date of the experiment (vessel in free route), . .	19th March, 1881.
Number of sets of indicator diagrams, taken half hourly,	20
Duration of the experiment, in hours and minutes, consecutively, ...	10

Total number of pounds consumed of Nixon's navigation steam coal,	1770·8680
Total number of pounds of refuse, in ash, etc., from the coal,	88·5434
Total number of pounds of combustible (gasifiable portion of the coal) consumed,	1682·3246
Per centum of the coal in refuse of ash,	5·
Total number of double strokes made by the pistons of the engine,	63650·

ENGINE.

Steam pressure in the boiler, in pounds per square inch above the atmosphere,	395·15
Steam pressure in the receiver, in pounds per square inch above the atmosphere,	18·90
Position of the throttle valve,	Wide open.
Fraction completed of the stroke of the piston of the 1st cylinder when the steam was cut off,	0·6077
Fraction completed of the stroke of the piston of the 3d cylinder when the steam was cut off,	0·2643
Number of times the steam was expanded,	22·9154
In none of the cylinders was the steam cushioned, nor was there either steam or exhaust lead,	.....
Vacuum in the condenser, in inches of mercury	28·75
Back pressure in the condenser, in pounds per square inch above zero,	0·575
Number of double strokes made per minute by the steam pistons,	106·0833

TEMPERATURES.

Probable temperature, in degrees Fahrenheit, of the feed water,	122·0
Temperature, in degrees Fahrenheit, of the boiler steam, considered as saturated,	438·0
Temperature, in degrees Fahrenheit, of the steam in the valve chest of the 1st cylinder,	422·5
Temperature, in degrees Fahrenheit, of the steam in the 1st cylinder at the commencement of the stroke of the piston, considered as saturated,	416·3
Temperature, in degrees Fahrenheit, of the air in the air space between the side of the 1st cylinder and its lagging,	314·6
Temperature, in degrees Fahrenheit, of the water of condensation from the steam jacket of the 1st cylinder,	418·5
Temperature, in degrees Fahrenheit, of the water of condensation from the steam-jacket of the 2d cylinder,	409·8
Temperature, in degrees Fahrenheit, of the water of condensation from the steam-jacket of the 3d cylinder,	404·0

Rate of Combustion.

Pounds of coal consumed per hour,	177·0868
Pounds of combustible consumed per hour,	168·2325
Pounds of coal consumed per hour per square foot of grate,	11·5624
Pounds of combustible consumed per hour per square foot of grate,	10·9842
Pounds of coal consumed per hour per square foot of outer heating surface,	0·2832
Pounds of coal consumed per hour per square foot of inner heating surface,	0·3811
Pounds of combustible consumed per hour per square foot of outer heating surface,	0·2691
Pounds of combustible consumed per hour per square foot of inner heating surface,	0·3620

Steam Pressures in First Cylinder, Per Indicator.

Pressure on piston of 1st cylinder at commencement of its stroke, in pounds per square inch above zero,	317·69
Pressure on piston of 1st cylinder at the point of cutting off the steam, in pounds per square inch above zero,	261·44
Pressure on piston of 1st cylinder at end of its stroke, in pounds per square inch above zero,	175·94
Mean back pressure against piston of 1st cylinder during its stroke, in pounds per square inch above zero,	79·6000
Back pressure against piston of 1st cylinder at commencement of its stroke, in pounds per square inch above zero,	58·38
Indicated pressure on piston of 1st cylinder, in pounds per square inch,	176·0625
Net pressure on piston of 1st cylinder, in pounds per square inch,	174·0625
Total pressure on piston of 1st cylinder, in pounds per square inch,	255·6625

Steam Pressures in Second Cylinder, Per Indicator.

Pressure on piston of 2d cylinder at commencement of its stroke, in pounds per square inch above zero,	103·39
Pressure on piston of 2d cylinder at end of its stroke, in pounds per square inch above zero,	44·46
Mean back pressure against piston of 2d cylinder during its stroke, in pounds per square inch above zero,	38·6334
Back pressure against piston of 2d cylinder at commencement of its stroke, in pounds per square inch above zero,	36·50
Indicated pressure on piston of 2d cylinder, in pounds per square inch,	24·5840

Net pressure on piston of 2d cylinder, in pounds per square inch,	22·5840
Total pressure on piston of 2d cylinder, in pounds per square inch, for the difference between the areas of the pistons of the 1st and 2d cylinders,	63·2174

STEAM PRESSURES IN THIRD CYLINDER, PER INDICATOR.

Pressure on piston of 3d cylinder at commencement of its stroke, in pounds per square inch above zero,	33·58
Pressure on piston of 3d cylinder at the point of cutting off the steam, in pounds per square inch above zero,	27·69
Pressure on piston of 3d cylinder at the end of its stroke, in pounds per square inch above zero,	10·03
Mean back pressure against piston of 3d cylinder during its stroke, in pounds per square inch above zero,	3·0755
Back pressure against piston of 3d cylinder at commencement of its stroke, in pounds per square inch above zero,	2·10
Indicated pressure on piston of 3d cylinder, in pounds per square inch,	16·3612
Net pressure on piston of 3d cylinder, in pounds per square inch,	14·3612
Total pressure on piston of 3d cylinder, in pounds per square inch, for the difference between the areas of the pistons of the 2d and 3d cylinders,	19·4367

HORSES-POWER.

Indicated horses-power developed in the 1st cylinder,	33·3736
Indicated horses-power developed in the 2d cylinder,	18·8080
Indicated horses-power developed in the 3d cylinder,	53·3489
Aggregate indicated horses-power developed in all three cylinders,	105·5305
Net horses-power developed in the 1st cylinder,	32·9945
Net horses-power developed in the 2d cylinder,	17·2777
Net horses-power developed in the 3d cylinder,	46·8301
Aggregate net horses-power developed in all three cylinders,	97·1023
Total horses-power developed in the 1st cylinder,	48·4821
Total horses-power developed in the 2d cylinder,	36·3558
Total horses-power developed in the 3d cylinder,	33·6362
Aggregate total horses-power developed in all three cylinders,	118·4741
Total horses-power developed by the expanded steam alone in the 1st cylinder,	17·5092
Total horses-power developed by the expanded steam in the 2d cylinder,	36·3558
Total horses-power developed by the expanded steam in the 3d cylinder,	33·6362

WEIGHT OF STEAM ACCOUNTED FOR BY THE INDICATOR.

Pounds of steam present per hour in the 1st cylinder at the point of cutting off the steam, calculated from the pressure there, ...	1043·9127
Pounds of steam present per hour in the 1st cylinder at the end of the stroke of its piston, calculated from the pressure there, ...	1125 2924
Pounds of steam condensed per hour in the 1st cylinder to furnish the heat transmuted into the total horses-power developed in that cylinder by the expanded steam alone, ...	42·9840
Sum of the two immediately preceding quantities, .	1168·2764
Pounds of steam present per hour in the 2d cylinder at the end of the stroke of its piston, calculated from the pressure there, ...	1192·7472
Pounds of steam condensed per hour in the 1st and 2d cylinders to furnish the heat transmuted into the total horses-powers developed in those cylinders by the expanded steam alone, ...	143·4642
Sum of the two immediately preceding quantities, .	1336·2114
Pounds of steam present per hour in the 3d cylinder at the end of the stroke of its piston, calculated from the pressure there, ...	1156·5362
Pounds of steam condensed per hour in the 1st, 2d and 3d cylinders to furnish the heat transmuted into the total horses-power developed in those cylinders by the expanded steam alone, ...	231·7806
Sum of the two immediately preceding quantities, .	1388·3168

WEIGHT OF WATER VAPORIZED IN THE BOILER FROM THE FEED TEMPERATURE.

Pounds of steam evaporated per hour in the boiler, .	1830·0000

NOTE.—In Mr. Bramwell's previous experiment of the 22d May, 1880, the pound of precisely the same coal vaporized, from the temperature of 122 degrees Fahrenheit and under the pressure of 371·69 pounds per square inch above zero, 10·418407 pounds of water; consequently, in the present experiment, it will vaporize from the same temperature, but under the pressure of 409·84 pounds per square inch above zero, 10·381482 pounds of water. Practically, this latter vaporization will be a little less, owing to the greater rapidity of the combustion and to the higher temperature of the iron heating surfaces of the boiler, and may be taken at 10⅓ pounds of water per pound of coal, from which the weight of steam evaporated per hour in the boiler, as given above, was calculated.

DIFFERENCE BETWEEN THE WEIGHT OF WATER VAPORIZED IN THE BOILER AND THE WEIGHT OF STEAM ACCOUNTED FOR BY THE INDICATOR.

Difference, in pounds per hour, between the weight of water vaporized (1830 pounds) in the boiler and the weight of steam	

accounted for by the indicator in the 1st cylinder at the point of cutting off the steam,	786·0873
Difference, in per centum of the weight of water vaporized in the boiler, between that weight and the weight of steam accounted for by the indicator in the 1st cylinder at the point of cutting off the steam,	42·96
Difference, in pounds per hour, between the weight of water vaporized in the boiler and the weight of steam accounted for by the indicator in the 1st cylinder at the end of the stroke of its piston,	661·7236
Difference, in per centum of the weight of water vaporized in the boiler, between that weight and the weight of steam accounted for by the indicator in the 1st cylinder at the end of the stroke of its piston,	36·16
Difference, in pounds per hour, between the weight of water vaporized in the boiler and the weight of steam accounted for by the indicator in the 2d cylinder at the end of the stroke of its piston,	493·7886
Difference, in per centum of the weight of water vaporized in the boiler, between that weight and the weight of steam accounted for by the indicator in the 2d cylinder at the end of the stroke of its piston,	26·98
Difference, in pounds per hour, between the weight of water vaporized in the boiler and the weight of steam accounted for by the indicator in the 3d cylinder at the end of the stroke of its piston,	441·6832
Difference, in per centum of the weight of water vaporized in the boiler, between that weight and the weight of steam accounted for by the indicator in the 3d cylinder at the end of the stroke of its piston,	24·14

Economic Results.

Pounds of coal consumed per hour per indicated horse-power,	1·6781
Pounds of coal consumed per hour per net horse-power,	1·8237
Pounds of coal consumed per hour per total horse-power,	1·4947
Pounds of combustible consumed per hour per indicated horse-power,	1·5951
Pounds of combustible consumed per hour per net horse-power,	1·7325
Pounds of combustible consumed per hour per total horse-power,	1·4200
Pounds of feed-water consumed per hour per indicated horse-power,	17·3410
Pounds of feed-water consumed per hour per net horse-power,	18·8461
Pounds of feed-water consumed per hour per total horse-power,	15·4464
Fahrenheit units of heat consumed per hour per indicated horse-power,	19515·3167
Fahrenheit units of heat consumed per hour per net horse-power,	21209·1901

Fahrenheit units of heat consumed per hour per total horse-power,	17383·2182

PER CENTUM OF TOTAL PRESSURE ON PISTONS UTILIZED AS INDICATED AND AS NET PRESSURES.

Mean indicated pressure on the piston of the 3d cylinder, equivalent to the sum of the indicated pressure on that piston and of the indicated pressures on the pistons of the 2d and 1st cylinders, reduced respectively in the ratios of the areas of the pistons of the 2d and 1st cylinders to that of the 3d cylinder, and for the fact of the 2d and 1st cylinders being single acting, while the 3d cylinder is double acting, in pounds per square inch,	32·3643
Mean total pressure which applied to the piston of the 3d cylinder would produce the total horses-power developed by the engine,	36·3340
Per centum of the mean total pressure on the pistons of the three cylinders, utilized as indicated pressure,	89·08
Mean net pressure on the piston of the 3d cylinder, equivalent to the sum of the net pressure on that piston and of the net pressures on the pistons of the 2d and 1st cylinders, reduced respectively in the ratios of the areas of the pistons of the 2d and 1st cylinders to that of the 3d cylinder, and for the fact of the 2d and 1st cylinders being single acting, while the 3d cylinder is double acting, in pounds per square inch,	29·7787
Per centum of the mean total pressure on the pistons of the three cylinders utilized as net pressure,	81·96

BOILER VAPORIZATION.

Number of pounds of water that would have been vaporized in the boiler per hour had the feed-water been supplied at the temperature of 100 degrees Fahrenheit and vaporized under the atmospheric pressure of 29·92 inches of mercury,	1909·5022
Number of pounds of water that would have been vaporized in the boiler per hour had the feed-water been supplied at the temperature of 212 degrees Fahrenheit and vaporized under the atmospheric pressure of 29·92 inches of mercury,	2132·6096
Pounds of water vaporized from 100 degrees Fahrenheit by one pound of coal,	10·7823
Pounds of water vaporized from 100 degrees Fahrenheit by one pound of combustible,	11·3504
Pounds of water vaporized from 212 degrees Fahrenheit by one pound of coal,	12·0405
Pounds of water vaporized from 212 degrees Fahrenheit by one pound of combustible,	12·6742

COMPARISON OF MR. BRAMWELL'S FIRST AND LAST EXPERIMENTS.

As the screw of the *Anthracite* had a greater pitch, and as more coal was consumed per hour, during the last experiment than during the first, the conditions of the two varied as regards the number of double strokes made by the pistons per minute, the pressure of the steam and the power developed. The steam, too, was less expanded during the last experiment and less throttled, but it was greatly throttled in both, even with the throttle valve wide open, as in the last experiment, owing to the exceedingly small diameter of the steam pipe comparably with the space displacement per minute of the piston of the 1st cylinder.

In the last experiment, as compared with the first, the steam pressures in boiler and cylinders were much higher, the back pressure in the condenser much lower, the number of double strokes made by the pistons per minute much less, and the weight of coal consumed per hour much greater. To what extent each of these variable conditions affected the final result of the cost of the power in pounds of coal consumed per hour cannot be determined; but the result of their combination, if the comparison be made for the cost of the total horse-power in pounds of coal consumed per hour, which is the proper engineering comparison under the conditions, shows that the greater pressures, less expansion and less piston speed (the last experiment), gave $\left(\frac{1{\cdot}4947-1{\cdot}4291\times100}{1{\cdot}4291}=\right)$ 4·5903 per centum less economic efficiency than the lesser pressures, greater expansion and greater piston speed (first experiment). But as this difference may easily be within the limits of error for such experiments, nothing can be fairly concluded except for equality of economic performance in the two cases. The greater economy with which, on the contrary, the indicated horse-power was obtained during the use of the greater pressures, less expansion and less piston speed, was due simply to the better vacuum in the condenser in that experiment, which might, except for accidental circumstances, have been equally good for both experiments. The lower the mean total pressure in the large cylinder, the more important becomes the back pressure in the condenser. The still greater economy with which the net horse-power was obtained during the last experiment was due to the same cause, increased by the fact that the pressure required to work the engine, *per se*, being the same in both cases, was a larger proportion of the

less total piston pressure in the first experiment than of the greater total piston pressure in the last experiment. This realization usefully of a larger proportion of the total pressure on a piston when that pressure is higher than when it is lower, owing to the facts that the back pressure and the pressure required to work the engine, *per se*, are constant, is an undoubted advantage for higher mean total pressures on the piston, which will always exist, let the effect of other causes be what they may.

The two experiments clearly show that the cylinder condensations, exclusive of the condensation due to the development of the power by the expanded steam alone, were larger during the last experiment than during the first, a result which might have been anticipated from the greater initial pressure in the 1st cylinder and less back pressure in the 3d cylinder, joined with the much less speed of piston, notwithstanding the less expansion of the steam in the last experiment than in the first.

From the following table, in which will be found the principal quantities that influence the comparison of the two experiments, a clear idea may be had of the extent of the variations in the experimental conditions and of the resulting effects.

ENGINE.

	Mr. Bramwell's First Experiment.	Last Experiment.
Date of experiment,	22d May, 1880.	19th March, 1881.
Steam pressure in boiler in pounds per square inch above the atmosphere,	357·00	395·15
Steam pressure in boiler in pounds per square inch above zero,	371·69	409·84
Position of throttle valve,	Partly closed.	Wide open.
Number of times the steam was expanded,	26·8851	22·9154
Vacuum in the condenser in inches of mercury,	26·864	28·750
Number of double strokes made per minute by the pistons,	130·3881	106·0833

POWER.

Initial pressure on piston of 1st cylinder, in pounds per square inch above zero,	205·03	317·69
Back pressure against piston of 3d cylinder, in pounds per square inch above zero,	4·245	2·100

	Mr. Bramwell's First Experiment.	Last Experiment.
Aggregate indicated horses-power developed by the engine, . .	80·7323	105·5305
Aggregate net horses-power developed by the engine, . . .	70·3703	97·1023
Aggregate total horses-power developed by the engine, . .	96·6795	118·4741
Economic Results.		
Pounds of coal consumed per hour per indicated horse-power, . .	1·7114	1·6781
Pounds of coal consumed per hour per net horse-power, . . .	1·9634	1·8237
Pounds of coal consumed per hour per total horse-power, . . .	1·4291	1·4947
Equivalent Piston Pressures.		
Mean indicated pressure on the piston of the 3d cylinder, equivalent to the sum of the indicated pressure on that piston and of the indicated pressures on the pistons of the 2d and 1st cylinders, reduced respectively in the ratios of the areas of the pistons of the 2d and 1st cylinders to that of the 3d cylinder, and for the fact of the 2d and 1st cylinders being single acting, while the 3d cylinder is double acting, in pounds per square inch, .	20·1464	32·3643
Mean net pressure on the piston of the 3d cylinder in pounds per square inch, equivalent to the sum of the net pressure on the piston and of the net pressures on the pistons of the 2d and 1st cylinders, reduced as described immediately above, .	17·5608	29·7787
Mean total pressure on the piston of the 3d cylinder in pounds per square inch, equivalent to the sum of the total pressure on that piston and of the total pressures on the pistons of the 2d and 1st cylinders, reduced as described immediately above, .	24·1231	36·3340
Cylinder Condensation.		
Per centum of the weight of steam generated in the boiler, condensed in the 1st cylinder at the point of cutting off the steam, . . .	31·27	42·96

	Mr. Bramwell's First Experiment.	Last Experiment.
Per centum of the weight of steam generated in the boiler, condensed in the 1st cylinder at the end of the stroke of its piston, exclusive of the condensation due to the development of power by the expanded steam alone, ...	34·99	36·16
Per centum of the weight of steam generated in the boiler, condensed in the 2d cylinder at the end of the stroke of its piston, exclusive of the condensation due to the development of power by the expanded steam alone, ...	21·53	26·98
Per centum of the weight of steam generated in the boiler, condensed in the 3d cylinder at the end of the stroke of its piston, exclusive of the condensation due to the development of the power by the expanded steam alone, ...	8·47	24·14
COMBUSTION.		
Pounds of coal consumed per hour per square foot of grate surface, .	9·0213	11·5624

Registering Apparatus for Marine Cables.—The most perfect apparatus which has hitherto appeared for giving graphic signals upon the great submarine lines of cable is Sir Wm. Thomson's syphon recorder. There would be a great advantage in a telegraph which would register the signals of the mirror galvanometer. Paul Samuel proposes to use two selenium elements upon the screen where the light from the galvanometer is reflected: one at the right, the other at the left. Whenever one of them is illuminated its increased conductibility will enable it to act as a relay upon an electro-magnet, for marking upon a paper band the points and dashes of the Morse alphabet. He recommends the use of paper dipped in iodide of potassium, and of a triangle which will be moved so that the point will be controlled by one of the selenium elements and the base by the other; in the former case a dot will be produced, in the latter a dash.—*Les Mondes.* C.

RADIO-DYNAMIC FACTS.

By Pliny Earle Chase, LL.D.
Professor of Philosophy in Haverford College.

Before proceeding to demonstrate the fundamental propositions of photodynamics it may be well to give a list of some of the most important FACTS which have been added to the repertory of science by investigating the laws of action and reaction in elastic media. The original announcements of discovery may be found in the "Proceedings of the American Philosophical Society," unless otherwise stated.

1. The importance of the equations of "nascent" or dissociative velocity, $v = \frac{g\,t}{2}$, and of nascent modulus, $h = \frac{g t^2}{4}$; t representing the time of cosmical, molecular, or atomic rotation, and g representing the acceleration of a central force. Dec. 18, 1863.

2. Sun's annual and Earth's daily disturbances of atmospheric elasticity furnish data for estimating the distance and relative masses of the two disturbing bodies. Dec. 18, 1863.

3. Modification of the daily distribution of solar heat by cyclical elasticity and barometric pressure. March 4, 1864.

4. Mechanical modification of electric and magnetic currents. April 1, 1864; Oct. 6, 1865.

5. Oscillations produced by gravitating disturbances of molecular elasticity. April 1, 1864.

6. Polarizing influences of thermal convection and radiation. April 15, 1864.

7. Resemblance between lunar-monthly and solar-daily barometric fluctuations. June 17, 1864. Proc. Roy. Soc., June 16, 1864.

8. Combined influences of rotation, variations of temperature and vapor, solar and lunar attraction, and æthereal oscillations "moving with the rapidity of light," upon barometric fluctuations. July 15, 1864.

9. Numerical relations of gravity and magnetism. Oct. 21, 1864.

10. Resemblance between solar and lunar magnetic and atmospheric tides. Dec. 16, 1864.

11. Inverse relation of specific magnetism to coefficients of dilatation. May 19, 1865.

12. Control of magnetic needles by artificial currents resembling the normal atmospheric currents. Oct. 6, 1865.

13. Relations of temperature to gravity and density. Sept. 21, 1866.

14. Relation of terrestrial gravity to the velocity of light. Sept. 21, 1866.

15. Approximate equality in the influence of solar radiation and of atmospheric currents upon fluctuations of temperature. Feb. 1, 1867.

16. Demonstration of lunar influence upon rainfall by comparing different periods of observation at the same station. Dec. 4, 1868; Aug. 18, 1871; etc.

17. Equivalence of solar "nascent" or dissociative velocity (1) to the velocity of light. April 2, 1869.

18. Cosmical relations of light to gravity. April 2, 1869.

19. Frequency of anticyclonic storms and of local cyclones in general anticyclones. March 3 and 17, 1871.

20. Resemblance of atmospheric, magnetic and oceanic currents. April 7, 1871.

21. Identity of law in cosmical and molecular forces. Feb. 16, 1872.

22. Simple relations of explosive energy to Sun's mass and distance. Feb. 16, 1872.

23. Ratio of *vis viva* of wave-propagation to *vis viva* of oscillating particles. Feb. 16, 1872.

24. Influence of centres of oscillation and of the factor of linear *vis viva*, 9, on planetary masses, distances and cyclical motions. March 1, 1872.

25. Tendency of elastic vibrations to produce harmonic vibrations, illustrated by terrestrial rotation, lunar distance, lunar revolution and the velocity of light. April 5, 1872.

26. The same tendency illustrated by apsidal and mean planetary positions and eccentricities, by solar, planetary and lunar rotations, and by the sun-spot-cycle of 11·07 years. May 16, 1872.

27. Nebula-rupturing velocities acquired by subsidence from nr to $\frac{n}{n+1} r$. Sept. 20, 1872.

28. Evidences of parabolic projection between Sun and the nearest fixed star. Sept. 20, 1872.

29. Harmony of stellar and planetary positions with Sun's gravitating reaction against luminous undulation. Sept. 20, 1872.

30. Lunar influence on rainfall less affected by locality than solar. Nov. 1, 1872.

31. Influence of the circular ratio, π, upon planetary positions. Feb. 7, 1873.

32. Increased symmetry introduced by the supposed failure of "Bode's Law." March 7, 1873.

33. Musical intervals in the Fraunhofer lines. March 21, 1873.

34. Musical intervals in planetary positions. April 4, 1873.

35. Harmonic indications of intra-Mercurial planets. May 2, 1873.

36. Harmonic correlations of planetary mass. May 2, 1873.

37. Confirmation of harmonic prediction. Oct. 3, 1873.

38. The harmonic planetary progression closer than any other that has been pointed out. Oct. 3, 1873.

39. Mean proportionality of perihelion parabolic velocity between normal velocity of solar oscillation and the velocity of light. May 15, 1874.

40. Harmonic grouping of planets into pairs. May 15, 1874.

41. Harmonic influence of the centre of gravity of Sun and Jupiter on planetary masses, positions and motions. May 15, 1874.

42. Influence of luminous undulation on the secular eccentricity of Jupiter, terrestrial gravity and cosmical masses. Jan. 1, 1875.

43. Analogous equations in general physics, electricity, chemistry and cosmogony. June 18, 1875.

44. Circular ratio of velocity of dissociation to velocity of cohesion. June, 18, 1875.

45. Estimate of Sun's mass and distance from the tidal relations of magnetism and gravitation. June 18, 1875.

46. Combined planetary evidences of Fourier's theorem and of a universal elastic medium. Aug. 20, 1875.

47. Different atmospheric and nucleal rupturing tendencies in Herschel's statement of the nebular hypothesis, and consequent misapprehension of the laws of nucleal condensation. Sept. 17, 1875.

48. The nucleal radius, in a rotating condensing nebula, varies as the $\frac{2}{3}$ power of Laplace's limiting radius, or radius of possible atmosphere. Sept. 17, 1875.

49. Mathematical deduction of the ratio of heat under constant

volume to heat under constant pressure from the *vis viva* of gaseous volume and of uniform velocity. Dec. 3, 1875.

50. Harmonies of products and powers of planetary mass and distance. Dec. 3, 1875.

51. Various confirmations of Herschel's theory of subsidence. April 21, 1876.

52. Evidences of parabolic influence in chemical atomicity. Feb. 2, 1877.

53. Various nebula-rupturing tendencies of "subsidence." July 20, 1877.

54. Identity of law in spectral lines and planetary arrangement. Aug. 24, 1877.

55. Confirmation of Herschel's nebular theory by the moons of Mars. Jan. 18, 1878.

56. Harmonic wave-lengths in chemical elements. Jan. 18, 1878.

57. Harmonic arrangement of satellite-systems. Jan. 18, 1878.

58. Relation of planetary positions to the solar modulus of light. March 1, 1878.

59. The centre of greatest planetary condensation is in Earth's orbit; the nebular centre of planetary inertia, in Saturn's orbit; the centre of the Neptuño-Uranian nebula, in Jupiter's orbit. March 1, 1878.

60. Nine intra-Mercurial harmonic positions showing tendencies to synchronous oscillation and confirming harmonic prediction. Oct. 4, 1878.

61. Two additional confirmations of harmonic prediction. Feb. 21, 1879.

62. Harmonies of Lockyer's "basic lines." April 4, 1879.

63. Harmonic relations of the terrestrial day to the year. Dec. 19, 1879.

64. Relations between cosmical masses and positions. Jan. 2, 1880.

65. Various planetary relations between gravitating and luminous velocities. March 19, 1880.

66. Relation of ocean temperatures to Jóule's equivalent. April 16, 1880.

67. Relations of chemical affinity to luminous and cosmical energies. April 16, 1880.

68. Evidences of subsidence at the outer surface, and of rupturing

oscillation at the inner surface, of the two primitive planetary belts. Jan. 7, 1881.

69. Centrifugal as well as centripetal influence of paraboloidal projection between Sun and stars. Jan. 7, 1881.

70. Ratio of æthereal density to the density of hydrogen, deduced from the equality of action and reaction. Jan. 7, 1881.

71. Relation of masses, times and distances to luminous undulation. Jan. 21, 1881.

72. Three orders of harmonic spectra. April 15, 1881.

73. Cosmical significance of the corona line. April 15, 1881.

74. Stellar relations of the corona line and of mass. June 17, 1881.

75. Mutual convertibility of various natural physical units. June 17, 1881.

76. Relation of solar temperature to the natural terrestrial thermal unit. June 17, 1881.

77. Photo-dynamic and thermo-dynamic relations of the solar-stellar paraboloid. June 17, 1881.

78. Relations of Sun, Jupiter and Earth to photo-dynamic energy at the centre of greatest condensation. June 17, 1881.

In addition to the foregoing, there are more than two hundred subordinate facts which were discovered by studying the laws of æthereal action and reaction. A list of the papers in which they are enumerated was communicated to the American Philosophical Society, Nov. 5, 1880.

Radiophony.—E. Mercadier gives this name to the phenomenon discovered by Bell, in which an intermittent radiation of a definite period produces a sound of the same period. He has arrived by experiment at the following results: 1. Radiophony does not appear to be an effect of the receiving plate vibrating transversely, like an ordinary vibrating plate. 2. The nature of the molecules of the receiver and their mode of aggregation do not appear to exercise a predominant influence upon the nature of the sounds produced. 3. The sounds result from the direct action of the radiations upon the receivers. 4. The phenomenon seems to result principally from an action upon the surface of the receiver. 5. The radiophonic effects are relatively very intense. 6. They appear to be produced principally by calorific radiations or waves of great length.—*Compt. Rend.* C.

THE SCIENTIFIC PRINCIPLES INVOLVED IN ELECTRIC LIGHTING.

By Prof. W. Grylls Adams, F.R.S.

A series of "Cantor Lectures" delivered before the Society of Arts, London, 1881.

It has been well said that rarely does a great discovery, as soon as it is made, at once begin to furnish the results which follow as a natural consequence from it. Nearly all important discoveries pass through a stage of neglect or obscurity. Either the public attention is already pre-occupied, or the discoveries come at a time when the public are not prepared for them, and they are disregarded and may even disappear with their authors for a time, to come forward again with fresh force in after years, when the world is more in tune to receive them. Sometimes they pass through a stage of quiet development in the laboratory; laws are established, apparatus is devised to prove them, attention is drawn to them, public spirit is awakened and from the higher level of the great discoverer flow new facts and new inventions, with astonishing rapidity, in many channels; the potential energy of the discoverer is transformed into energy of action in many directions, with more or less efficiency according to the retarding state of the medium through which that action takes place.

The progress of electrical science in its several branches will afford abundant instances of these several stages. If, for instance, we regard the progress of telegraphy, we find that Sir Francis Ronalds, in 1816, showed that electricity could be practically used for conveying messages over long distances; yet so little notice is taken of his discoveries by the public and by the government, who were no longer in need (so they said) of telegraphs after the battle of Waterloo, that he is almost driven to despair, and speaks of "taking leave of a science which once afforded him a favorite source of amusement," and of "bidding a cordial adieu to electricity."

It is remarkable that he should have said sixty years ago, "Let us have electrical conversation offices communicating with each other all over the kingdom," and yet the electric telegraph was not established until 20 years after (1837), and we are only now arriving at the system of telephonic exchanges.

In a private letter, written on his 72d birthday, in 1860, he says, "If the electric telegraph of 1816 had been fairly examined, an effective instrument might have been in the hands of the government and, after Dr. Oersted's experiments (in 1820), an improved telegraph might have been in their hands."

We shall also see other instances in connection with the special subject of my lectures, in which discoveries are neglected and passed by because, as we say, the discoverers were men who were in advance of their time, and in some cases the same discoveries are again made, and become known under another name. In 1815, Sir Francis Ronalds constructed an electric engine, which was set in motion by means of Singer's electric columns, and as late as 1851 this engine was still in working order, when it was, I believe, at the Kew observatory.

In 1813, *i. e.*, when Ronalds was experimenting on the electric telegraph at Hammersmith, by means of his registering pith-ball electrometers, Sir Humphry Davy produced the electric light between two carbons, which were joined to the two poles of a powerful battery.

The following is a description of Sir Humphry Davy's experiments with the electric light:

"Mr. Pepys having had the goodness to charge the great battery of the London Institution, consisting of 2000 double plates of zinc and copper, with a mixture of 1168 parts of water, 108 parts of nitrous acid and 25 parts of sulphuric acid, so as to make an arc or column of electric light, varying in length from one to four inches, according to the state of rarefaction of the atmosphere in which it was produced, and a powerful magnet being presented to this arc or column, having its pole at a very acute angle to it, the arc or column was attracted or repelled with a rotatory motion, or made to revolve, by placing the pole in different positions, being repelled when the negative pole was on the right hand by the north pole of the magnet and attracted by the south pole."

With a few cells of some of the more powerful batteries, such as Grove's or Bunsen's, or the bichromate of potash battery, we may readily reproduce the celebrated experiment of Sir Humphry Davy.

When Davy discovered the electric light in 1813, little was known of voltaic electricity, except that the current decomposed salts, and was always accompanied by chemical action in the battery. Davy had obtained the metals potassium, sodium, barium, strontium, cal-

cium and magnesium by the electric current. The relation between electricity and magnetism was still unknown.

In the year 1820, Oersted first observed the action of a current of electricity on the magnetic needles, and thus gave a very ready method of comparing the effects of different currents, by balancing these effects on the needles against the effect of the earth's horizontal magnetic force. In the same year, Ampère discovered the law of the action of the current on the magnetic needles, and propounded his celebrated theory of magnets and of terrestrial magnetism. According to this theory, every particle of a piece of steel which forms the magnet has currents of electricity circulating round it in the same direction, and the magnetism of the magnet is only the resultant action of all these currents taken through the whole of the piece of steel. Thus magnetism is the resultant action of electric currents.

Ampère's experiments (which were repeated in the lecture) showed the mutual attraction and repulsion of parallel currents and of currents and magnets; also that a current in a solenoid or in a flat coil acts as a magnet; and that a hollow coil carrying a current attracts a core of soft iron and holds it up.

These elementary experiments are now very simple, and they may be very well known; but, as we shall see in the lectures which are to follow, some of these early and simple devices are found to be among the most efficient for controlling and regulating the current and steadying the light in some of the best electric lamps. Whilst Ampère was developing Oersted's experiment in one direction, Schweigger, in the same year (1820) employed it for the comparison of currents and invented the galvanometer. Then followed improved galvanometers by Becquerel and others; and, in 1827, Ohm gave his simple theory of the action of batteries, which was deduced from Volta's principle, and this has formed the groundwork of all later investigations of the subject.

If we consider these simple experiments of Oersted and Ampère in their relation to the now well-established principles of conservation of energy, we may arrive at some important conclusions which again are fully borne out by experiment. Thus, when a current of electricity passes along a wire in Oersted's experiment, part of its energy is spent in overcoming the resistance of the wire and another part is spent in causing the motion of the magnetic needle, *i. e.*, in doing work upon it in opposition to the pull of the magnetic force of the

earth upon it. This part of the energy, which is spent in twisting the magnetic needle about the axis, leaves less energy to be spent in producing the current, and so there is less current passing in the wire when the magnet is in the act of being deflected than there is in the same wire when there is no magnet. When the magnet is held at rest, or when it has settled into its position of rest, there is no longer any energy spent in keeping it there, and the full current again passes in the wire. Thus a current which deflects a magnet is itself diminished by that motion of the magnet. Take, again, any of the simple experiments of Ampère on the mutual action of currents of electricity upon one another and the motion of conductors carrying those currents. There is a conversion of energy of the current into motion of the conductor carrying the current in parallel wires attracting one another, and hence there is less current in the wire while the motion is actually taking place. Thus the approach of two wires carrying currents of electricity diminishes the currents flowing in the wires.

Now if the approach of these wires diminishes the currents in them, then the separation of the wires may be expected to increase the currents flowing in them, for in the separation work is done in the opposite direction. Hence, in the alternate approach and separation of the wires as they oscillate, the currents are diminished and increased alternately. If there be no current at all in one of the wires, then the separation of the two wires will give a current in the one which had no current in it, and the approach of the wires will give a current in the opposite direction. Thus we are led, by the well-known principles of energy, to results which are well known to be true by experiment, that the separation of the parallel wires, one of which is carrying a current of electricity, produces in the other wire a current of electricity in the same direction or a direct current, and their approach produces a current of electricity in the opposite direction, or an inverse current.

Let us pursue this relation of the principles of energy to the effects produced by electric currents a little further. With two parallel currents in two approaching wires, the amount of energy used up, and therefore producing no effect in the shape of current, depends on the amount required or expended in bringing the wires together. This depends on the rate at which they approach one another. The more rapidly they approach, the more energy is consumed, and the more the currents in the wires are diminished.

In the same way, if the wires are separating from one another, the currents are increased by an amount which depends upon the rate of their separation. Hence, not only their relative motion, but the rate at which they approach and recede from one another, will determine the changes produced in the electric currents in them.

As in the case of bodies falling under the action of the force of gravity, the amount of energy expended is measured by the square of the velocity of falling, so, in the case of currents of electricity in wires approaching one another, the energy expended is measured by the square of the velocity of approach; so that the alteration in the current takes place more and more rapidly as the rate of approach is increased. If, again, we apply this to the case where one of the wires has a current in it, and a second parallel wire has no current in it as long as it remains at rest, then the amount or strength of the direct current in the second wire will increase at a more and more rapid rate as the velocity of the separation of the wires is increased, and the strength of the inverse current in the second wire will increase at a more and more rapid rate as the velocity of approach of the wires is increased.

Here, then, we have the laws of the production of induced currents deduced according to the principles of energy from the relative motion of parallel currents, discovered by Ampère. These laws are of such importance in connection with the subject of these lectures, that I shall illustrate them a little farther by a few simple experiments, showing the effect of rate of approach or separation on the induction current.

Instead of actually removing the coils, if the current in the primary circuit be diminished, the effect is the same as if a wire carrying a part of it had been taken away, and so there is a direct current induced in the secondary wire, whereas, if the current in the primary wire be increased, the effect is the same as if a wire carrying the additional current had approached, and so an inverse current is induced in the secondary wire.

We shall get the greatest rate of separation by suddenly stopping the current in or breaking the primary current, and the greatest rate of approach by suddenly joining or making the current flow in the primary circuit. Hence, breaking the primary circuit produces a very intense rush of electricity, giving a direct current of great intensity in

the secondary wire; and making the primary circuit gives a powerful inverse current in the secondary wire.

Having shown the relation between the production of currents of electricity by induction and the experiments of Ampère, as we should regard them at the present day in their relation to the principles of energy, let us now consider for a few minutes the way in which they were first produced.

It is now just fifty years ago since Faraday communicated to the Royal Society his first series of papers, entitled: (1.) On "The Induction of Electric Currents;" (2.) on "The Evolution of Electricity from Magnetism;" (3.) on "A New Electrical Condition of Matter;" and (4.) on "Arago's Magnetic Phenomena."

Little did he imagine the marvelous results that were to flow from his experiments when he wrote, at the beginning of that communication, that he had been stimulated to investigate experimentally the inductive effects of electric currents, with the view of elucidating Ampère's beautiful theory of magnetism, and, in the hope of obtaining electricity from ordinary magnetism. In those papers he describes most minutely the details of his experiments, and unfolds, step by step, the laws of an induction current in the helix of wire, called B, placed near to another helix, called A, carrying a voltaic current. That, as long as a steady current was maintained in A, there was no current induced in B; that, on making contact in A, or on approaching the wires, there was a momentary inverse current in B, and, on breaking contact in A, or on separating the wires, there was direct induced current in B; that, as this current was of the nature of an electric wave, like the shock of a Leyden jar, it might magnetize a steel needle, although it produced slight effect on a galvanometer, and how his expectation was confirmed, and that the needle was magnetized opposite ways on making and on breaking contact.

Then, in his evolution of electricity from magnetism, he gives an account of the greatly increased effects on introducing soft iron cores into his helices of wire, and shows that similar effects are obtained by using ordinary magnets in place of a helix carrying a battery current round an iron core, *i. e.*, in place of an electro-magnet. Also, in place of a cylinder of iron in a helix of wire, he uses a welded soft iron ring, 6 inches in diameter, and $\frac{7}{8}$ of an inch in thickness, with helices wound round it—in fact, what would now be called a Gramme ring—and remarks that the iron cylinder arrangement was not so powerful

as the ring arrangement. Placing the core within the helix, he magnetizes it by bringing permanent magnets in contact with its ends, and observes "a deflection which indicates an induced current of electricity in the opposite direction to that fitted to form a magnet, having the same polarity as that really produced by contact with the bar magnets." Such a current would have converted the cylinder into a magnet of the opposite kind to that formed by contact with the poles A and B, and such a current moves in the opposite direction to the currents which in Ampère's beautiful theory are considered as constituting a magnet in the position figured. On bringing the bar in contact with the poles of the magnet, a current is induced in the wire in the direction indicated in the figure.

He then describes the experiment of introducing a magnet with a coil of wire, and shows that the same current is obtained whether the marked end of the magnet be introduced at one end of the coil or the unmarked end introduced at the other, and that a current is produced in the opposite direction to the former on withdrawing the magnet from either end.

Then after describing the method of producing his induction spark, and also muscular contractions in a frog by means of a loadstone and coils, which were lent to him from King's College, and remarking that the intensity of the effect produced depends upon the rate of separation of the coil from the polls of the loadstone, he concludes this section thus: "An agent which is conducted along metallic wires in the manner described, which, whilst so passing, possesses the peculiar magnetic actions and force of a current of electricity, which can agitate and convulse the limbs of a frog, and which finally can produce a spark, can only be electricity."

One other of the discoveries of Faraday, made in that memorable year 1831, we shall find to be of great importance in magneto-electric machines, viz., the difference of time between induction by a battery current in a coil and induction by a magnet, which requires a considerable interval of time to get up to its full strength. Faraday accounted for this retardation by supposing that there is a redistribution of the Ampèrian currents in the iron itself, so that the magnet requires time to rise to its full power.

We may well consider for a while the work of such a man, who, fifty years ago, in his first series of papers to the Royal Society, could establish so many laws of magnetic and current induction, and who

made possible the rapid development which is now going on in the science of electricity, and especially in the production of magneto- and dynamo-machines.

After the discovery of the principles which I explained in the last lecture, and the method of producing currents of electricity by the inductive action of magnets, or currents in motion, the laws of these currents were being developed; but, for twenty years after Faraday's discovery in 1831 that the sudden removal of a coil of wire from the pole of a magnet gave rise to a current, nothing was done to apply these laws for the purposes of electric lighting. Voltaic batteries were being improved, and the more constant and more powerful batteries of Daniell, and Grove, and Bunsen were discovered, and these were the sources employed to produce the more powerful currents of electricity. In this country Grove's battery was the favorite; and in our laboratories we may say that, up to the present time, the 40 or 50 cells of Grove have always been used to give us the electric light.

When used for optical experiments in the laboratory, the source of light should be as steady as possible, and as the carbons burn away, their points should be continually brought to the same position; hence the elaborate arrangements of wheel work and electro-magnets devised by Staite, in 1847, and by Foucault, which have reached very great perfection in the hands of Duboscq.

One of the carbons, that connected with the positive pole of the battery, burns away twice as fast as the other, and hence the wheel work must be adapted for feeding these carbons automatically at the proper rate.

When the current flows always in the same direction in the arc, as in this case where Grove's battery is used, and in all cases where the magneto-machine is adapted for producing continuous currents, the positive charcoal point or carbon becomes hollow, and wears away more rapidly; and the negative carbon becomes pointed, and wears away about half as fast.

In the Duboscq lamp, the positions of the points of the carbon are kept as nearly as possible the same; the carbons are moved towards one another by means of a drum carrying two wheels, whose diameters are as two to one, which move two racks, which carry the carbons towards one another. This lamp is far too complicated and delicate in its mechanism to use with magneto-electric machines, and

therefore the system adopted in it, for regulating the current and regulating the carbons, requires considerable modification, before this lamp can be adapted for general use for the purposes of electric lighting. It is especially adapted for use with optical apparatus, and for showing by projection on the screen the special characteristics of the arc formed by the glowing gases of various substances. We may use it now for showing the character of the arc formed by silver converted into a glowing gas by the intense heat of the arc. This arc shows us that silver is rich in the violet or chemical rays, and points to the reason why the salts of silver are of so much use in photography.

Electric Regulators or Governors.

By the laws of Ohm we get the relation between the electro-motive force, the current, and the resistance expressed by the statement:

The product of the current by the resistance in a circuit is equal to the electromotive force in that circuit, or $E = C(R + r)$.

Regulators may act so as to control:

1. The electromotive force and internal resistance of the battery or dynamo-electric machine.

2. Or they may control the useful resistance in the circuit.

3. Or they may control the external resistance, which does not produce useful work.

Regulators which control the current by altering the electromotive force or internal resistance of the source of electricity, so as to counterbalance other distributing effects, are not practically of much importance, and so need not detain us long. Suppose, for instance, that an increase of current acted on a rotating governor in such a way as to raise the plates out of the battery, thereby increasing the internal resistance, this would diminish the currents which would so react on the governor, and again lower the plates. Or suppose the current passes round a coil which is set with its axis vertical, and that an iron rod supports the carbon and zinc in a bichromate of potash battery, and passes into the axis of the coil, then, as the current increases, the coil draws up the iron core and the battery plates, and increases the internal resistance, which diminishes the current.

Regulators which act on the useful resistance in the circuit, *i. e.*, in the case of electric lighting, the different arrangements made in electric lamps for producing steady currents between the carbon points,

by keeping them the same distance apart, are very numerous, and I hope to treat of them in a future lecture.

Another kind of regulator controls the current by varying the external resistance of the circuit, so that when the current increases an additional resistance is thrown into the circuit, and when the current diminishes the external resistance is diminished. If a machine is working with the greatest efficiency, then the addition of external resistance will diminish that efficiency, so that a regulator which varies the external resistance diminishes the efficiency of the machine in order to maintain a steady current.

There are many ways of varying the external resistance of a circuit; for instance, a rheostat set in action by clockwork, which is started by an armature of an electro-magnet placed in the circuit. If, for instance, as the current is weakened, the armature of the electro-magnet falls and releases a wheel of a clockwork arrangement, which diminishes the resistance by unwinding the wire of the rheostat. The methods which have been employed have been gradually simplified, and it is found that the simplest means are at the same time the most efficient. For weak currents, Edison's system, whereby a greater or less pressure on powdered carbon increases or diminishes its conductivity, has been employed. Edison also devised a regulator or shunt for the current, by the expanding of a platinum spiral wire placed in the lamp which short-circuited the current on reaching a certain definite temperature. Suppose, for instance, that an arrangement is made by which, when a current increases, part of it is sent through an electro-magnet, which draws up an arm so as to break the direct circuit, and send all the current through the electro-magnet, the resistance of the coil of the electro-magnet reduces the current, the arm falls, and again the current passes through the direct circuit.

Lane-Fox Regulator.

The regulator is an electro-magnet of very high resistance, which takes a branch of the current and acts on one end of a lever. The other end of the lever makes contact with one or other of two pins, which are connected with one or other of two coils forming electro-magnets, called respectively H and K, which govern either the throttle valve of the steam engine, or which may be made to introduce extra resistance by sliding contact over the wires of a rheostat. When the lever touches one of the pins, a current passes through the lever to

the electro-magnet H and turns the arm in one direction, and when it touches the other pin, the arm turns in the opposite direction, so that in one case the resistance of the circuit is increased and in the other it is diminished.

Siemens Regulator.

By means of the expansion of a fine strip of mild steel or fused iron stretched between two points, when the electric current passes through it, a vertical spindle, supporting a circular metallic disc, with platinum contacts on its upper surface, is lowered, so that the contacts of platinum, with certain points in a helical rheostat, are broken one by one, and at each break an additional portion of the rheostat is thrown into the circuit, and so the excess of current is checked. For the normal current the rheostat is out of circuit, but an excess of current heats the wire, lowers the platinum contacts, and brings more or less of the rheostat into the circuit. For small variations of current, the change of current is nearly proportional to the change of temperature in the strip.

Methods of Measuring Electric Currents.

There are four principal methods of measuring powerful electric currents.

1. *The Galvanometer Method.*--With a tangent galvanometer of small resistance, it is necessary to bring the deflections to about 45° by a shunt of very small resistance, which sends only a very small part of the current through the galvanometer. Here there is a liability to error in the measurement of the resistance of the shunt. The objection to this method is that a small quantity is measured by the galvanometer, and the error of the observation is multiplied, it may be a thousandfold, or even very much more, in order to arrive at any idea at all of the total current flowing in the principal circuit. I can only compare the method to an attempt to estimate the flight of starlings, or of a covey of birds, by measuring or marking, as accurately as possible, the flight of one particular bird which has been separated from the rest, and which is assumed to travel at the same rate, no matter what obstructions or attractive influences may have come across its path. At the same time, the difficulties of these measurements are so great that any method may be of great service, and this method has been employed by several observers with good results.

For strong currents, instead of a tangent galvanometer, Professor Trowbridge, of Harvard University, employs a galvanometer in which

the coil carrying the current is capable of turning about a horizontal axis, passing through the centre of the needle. When the coil is vertical the instrument is a tangent galvanometer; but on turning the coil through any angle, the part of the current which deflects the needle will be diminished: by this the current has very little effect in turning the needle when the coil is near the horizontal position.

2. *The Electrometer Method.*—The difference of potential between two points in a closed circuit may be measured directly, either by an electrometer like Thomson's quadrant electrometer, or by balancing the electromotive force between the two points, by a battery of the same electromotive force, in the circuits of which a galvanometer is placed, in which case the electromotive force is found by finding at what points the wires from the battery shall be attached, so that no current shall pass through the galvanometer. An instrument for the purpose I have described is Clark's potentiometer. This method has been employed Dr. Hopkinson and by others, to determine the current produced by a Siemens machine for the electric light. It has also been applied by Mr. Joubert and others to determine the current required to make the Jablochkoff candle burn at its best, and also for the estimation of the current given both by continuous current machines and also by alternate current machines for producing the electric arc.

3. *Method of Using Thomson's Electrometer.*—If V be the potential of the needle, and V_1 V_2 the potential of the quadrants and d the deviation of the needle, k being a constant, then

$$d = k\,(V_1 - V_2)\left(V - \frac{V_1 + V_2}{2}\right)$$

But, if the needle and one pair of quadrants be connected,

$$d = \frac{k}{2}\,(V_1 - V_2)^2, \text{ where } V = V_1$$

so that the deviation is proportional to the square of the difference of potential, and is therefore independent of the direction of the current.

By means of two electrometers so arranged, the current and energy expended between any two points of a circuit may be at once determined. First consider the case of a continuous current. Let one electrometer have its poles attached to two points, A and B, of the circuit where the potentials are V_1 and V_2, having a resistance, r_1, between them and a current, C, then

$$Cr_1 = V_1 - V_2.$$

Now take two other points, C and D, in the same circuit, which

have a difference of potential, $V_3 - V_4$, and which have an electromotive force, E, as well as a resistance, r_2, between them, then

$$E + Cr_2 = V_3 - V_4.$$

Then the energy expended between these two points is

$$C(E + Cr_2) = \frac{(V_1 - V_2)(V_3 - V_4)}{r_1},$$

so that the deflection of the two electrometers will at once give the

$$\text{Energy expended} = \frac{2}{r_1}\sqrt{\frac{d_1 d_2}{k_1 k_2}}.$$

One electrometer gives the current, and the two together give the work expended.

If, instead of a continuous current, we have alternate currents succeeding one another at intervals which are very short compared with the time of oscillation of the needle, then the needle will remain steadily deflected at a deviation proportional to the mean value of the square of the difference of potential:

$$d = \frac{k}{2}(V_1 - V_2)^2.$$

In this case the difference of potential must be measured absolutely at the same instant. This may be done by placing two contact breakers on the revolving axis of the dynamo machine, so arranged that by both of them contact is made and broken at the same instant some 20,000 times in a second, then the two electrometers will give the desired results. In place of the electrometer which is employed to give the strength of current, a galvanometer may be employed, as in Clark's potentiometer, in which case it is only necessary to have one contact breaker, and so the arrangements are more easily made.

The law of variation of the current in alternate current machines may be obtained by the law of variation of the resistance for different periods of contact, *i. e.*, for different phases of rotation of the contact breaker. Thus the different phases of the current may be studied by dividing the period into a certain number of equal parts, and, by means of the contact breaker, making contact only at the same phase of the period of revolution.

The intensity of the light at the different phases of the period may also be studied and measured by means of revolving discs with holes in them, arranged so as to let light through only at the proper instant. The result of experiments is that the law of increase of current in alternate current machines is the law of simple harmonic motion, but

the maximum effect does not occur at the normal position, but is displaced in the direction of the motion: Experiments, of which a full account has been given in *La Lumière Electrique*, have shown that even with coils alone there is a retardation of the inductive action arising from the induction of a current on itself. The retardation is about $\frac{1}{8}$ of the whole period, even with a bobbin without a soft iron core, and this displacement is independent of the velocity, and rigorously the same for 400, 700 or 1000 turns in a minute. In the case of magneto-electric machines, there is a retardation which is usually attributed to the retardation of magnetization of the magnet, but that does not apply to the case of coils, in which case the retardation depends on the self-induction of the current. By the above method, the fall of potential between the carbons in the arc may be measured at different phases of the period of revolution. Thus it is found that at the instant when the circuit is made there is no difference of potential, but in an indefinitely short time the electromotive force rises to 40 or 45 volts, and remains at that value almost without change until the current again becomes very feeble, and then the electromotive force suddenly falls. The difference of potential in the arc seems to be constant within very wide limits for the values of the current. The conclusions arrived at by M. Joubert are that the resistance of the arc is very small; that it varies with temperature and diminishes as the temperature increases. The difference of potential between the two carbons is due to an electromotive force, which is independent of the current, and which is estimated by him at 30 volts. Particles pass between the carbons just as between the electrodes in a voltameter. There seems to be an action like polarization, and the work done depends only upon, and is proportional to, the quantity of electricity which passes.

Another method of measuring the currents which is applicable to both continuous currents and to obtain the average values of alternate currents, depends on the development of heat in an electric circuit. It was shown by Joule, and follows from the law of transformation of energy, that the heat developed by a current, C, in a resistance, r, in time, t, is $C^2 r t$, hence the current, C, may be measured by the quantity of heat received in a given time by water, in which a resistance, r, is immersed. This method has been employed by Dr. Siemens, and was one of the methods employed by Dr. Hopkinson in measuring electric light currents.

In his experiments Joule inserted a wire of known resistance in a given quantity of water placed in a calorimeter, and measured the change of temperature of the water, and also measured the current, and found that $H = C^2 r t$, where H is the quantity of heat produced by the current.

The Electro-Dynamometer Method.—There is still another method of measuring currents, which Maxwell says "is probably the best fitted for absolute measurements."

In Weber's electro-dynamometer one coil is suspended within another by means of two fine wires, through which the current is led to the suspended coil. This arrangement is not suitable for powerful currents, because shunts become necessary, and because the suspended wires become heated.

An electro-dynamometer on the same principle has been devised by Dr. C. W. Siemens, who has kindly lent me one of his instruments for these lectures.

Attached to a binding screw is one end of a fixed coil or bobbin, across which a single turn of copper wire with its ends dipping into two mercury cups, is freely suspended in a vertical plane, so as to turn about a vertical axis. One of the mercury cups is electrically connected with a binding screw, and the other with one end of the fixed coil, so that the same current passes through the fixed coil and suspended wire. When the current passes, the suspended wire tends to turn about a vertical axis, but its motion is counteracted by a torsion spring, to one end of which the wire is attached, the other end being fixed to a socket carrying an index, which must be moved over a graduated circle, so as to bring the suspended wire back to its initial position. The action between the currents in the coils, and therefore the torsion which measures it, is proportional to the square of the current. By increasing the number of turns in the fixed coil, and having only one turn in the suspended wire, the action of the earth's magnetism on the current in the suspended wire may be neglected in comparison with the action of the fixed coil upon it, so that the position of the plane of the magnetic meridian at the place of observation may be disregarded in using this instrument. There are usually two fixed coils or bobbins; one coil, attached to a binding screw, being of a small number of turns of thick wire for continuous currents, and the other, attached to a similar binding screw, being much longer and

finer, for use with machines giving alternate currents or currents of high tension.

An electro-dynamometer has also been devised by Professor Trowbridge, of Harvard University, in which there are two large fixed coils made from copper bands, between which is suspended from a torsion head a small coil with mercury connections, so that all the current passes through each coil. This instrument has been improved by Mr. W. N. Hill, who limits the swing of the central coil, and measures the current by bringing the coil back to its zero position, by balancing the force of repulsion of the coils by weights placed in two scale pans, one on each side of the instrument, so as to balance the action of the current by torsion of the suspending wire. If C be the current, $w\,l$ the twisting moment of the weight, w, G and g the constants for the two coils, and k the constant of the instrument,

$$\text{then } C^2 = \frac{l\,w}{k\,G\,g}$$

G and g are found by measurement, and k is found by comparison with another instrument. Through the kindness of Messrs. Elliott Brothers I have the opportunity of bringing before you an electro-dynamometer of this form with the latest improvements. This form of dynamometer is especially applicable for large currents, since the weights required to bring the deflection to zero increase as the square of the current, and so greater accuracy may be attained.

(To be continued.)

Mechanical Imitation of Electric and Magnetic Actions.—Chase's apparatus for imitating "lines of force" and showing a mechanical control of magnetic currents has furnished a precedent for many similar contrivances. One of the latest is that of M. C. A. Bjerknes, for the hydrodynamic imitation of electric and magnetic actions. The inventor proposes to use his apparatus not only for the investigation of known laws, but also for the discovery of laws and methods which have been hitherto unknown. He has been for some time occupied upon the study af oscillations of various kinds. His attention appears to have been turned in this direction by the acoustic attractions and repulsions which were experimentally examined by Guyot, Schellbach and Guthrie, and which have been partially studied mathematically by Sir Wm. Thomson.—*Comptes Rendus.* C.

INDIGO AND ITS ARTIFICIAL PRODUCTION.

By H. E. Roscoe, LL.D., F.R.S., President of the Chemical Society.

A paper read before the Royal Institution of Great Britain, Friday, May 27, 1881.

More than eleven years ago the speaker had the pleasure of bringing before this audience a discovery in synthetic chemistry of great interest and importance, viz., that of the artificial production of alizarin, the coloring substance of madder. To-day it is his privilege to point out the attainment of another equally striking case of synthesis, viz., the artificial formation of indigo. In this last instance, as in the former case, the world is indebted to German science, although to different individuals, for these interesting results, the synthesis of indigo having been achieved by Professor Adolf Baeyer, the worthy successor of the illustrious Liebig in the University of Munich. Here, then, we have another proof of the fact that the study of the most intricate problems of organic chemistry, and those which appear to many to be furthest removed from any practical application, are in reality capable of yielding results having an absolute value measured by hundreds of thousands of pounds.

In proof of this assertion, it is only necessary to mention that the value of the indigo imported into this country in the year 1879 reached the enormous sum of close on two millions sterling, whilst the total production of the world is assessed at twice that amount; so that if, as is certainly not impossible, artificial indigo can be prepared at a price which will compete with the native product, a wide field is indeed open to its manufacturers.

Indigo, as is well known, is a coloring matter which has attracted attention from very early times. Cloth dyed with indigo has been found in the old Egyptian tombs. The method of preparing and using this color is accurately described by both Pliny and Dioscorides, and the early inhabitants of these islands were well acquainted with indigo, which they obtained from the European indigo plant, *Isatis tinctoria*, the woad plant, or pastel. With this they dyed their garments and painted their skins. After the discovery of the passage to India by the Cape of Good Hope, the Eastern indigo, derived from various species of *Indigofera*, gradually displaced woad, as containing more of

the coloring matter. But this was not accomplished without great opposition from the European growers of woad; and severe enactments were promulgated against the introduction of the foreign coloring matter, an edict condemning to death persons "who used that pernicious drug called devil's food" being issued by Henry the Fourth of France. The chief source of Indian indigo is the *Indigofera tinctoria*, an herbaceous plant raised from seed which is sown in either spring or autumn. The plant grows with a single stalk to a height of about 3 feet 6 inches, and about the thickness of a finger. It is usually cut for the first time in June or July and a second or even a third cutting obtained later in the year. The value of the crop depends on the number of leaves which the plant puts forth, as it is in the leaves that the coloring principle is chiefly contained. Both the preparation of the coloring matter from the plant and its employment as a dye or as a paint are carried on at the present day exactly as they have been for ages past. The description of the processes given by Dioscorides and Pliny tally exactly with the crude mode of manufacture carried on in Bengal at the present day, as follows:

"The Bengal indigo factories usually contain two rows of vats, the bottom of one row being level with the top of the other. Each series numbers from fifteen to twenty, and each vat is about 7 yards square and 3 feet deep; they are built of brickwork, lined with stone or cement. About a hundred bundles of the cut indigo plants are placed in each vat in rows and pressed down with heavy pieces of wood; this is essential to the success of the operation. Water is then run in so as to completely submerge the plants, when a fermentation quickly ensues, which lasts from nine to fourteen hours, according to the temperature of the atmosphere. From time to time a small quantity of the liquor is taken from the bottom of the vat to see how the operation is proceeding. If the liquor has a pale yellow hue, the product obtained from it will be far richer in quality but not so abundant as if it had a golden-yellow appearance. The liquor is then run off into the lower vats, into which men enter and agitate it by means of bats or oars, or else mechanically by means of a dash-wheel, each vat requiring seventeen or eighteen workpeople, who are kept employed for three or four hours. During the operation, the yellow liquor assumes a greenish hue and the indigo separates in flakes. The liquor is then allowed to stand for an hour and the blue pulpy indigo is run into a separate vessel, after which it is pumped up into a pan and

boiled, in order to prevent a second fermentation, which would spoil the product by giving rise to a brown matter. The whole is then left to stand for twenty hours, when it is again boiled for three or four hours, after which it is run on to large filters, which are placed over vats of stonework about 7 yards long, 2 yards wide and 1 yard deep. The filters are made by placing bamboo canes across the vats, covering these with bass mats and over all stretching strong canvas. The greater part of the indigo remains under the form of a dark-blue or nearly black paste, which is introduced into small wooden frames having holes at the bottom and lined with strong canvas. A piece of canvas is then placed on the top of the frame, a perforated wooden cover, which fits into the box, put over it and the whole submitted to a gradual pressure. When as much of the water as possible has been squeezed out, the covers are removed and the indigo allowed to dry slowly in large drying sheds, from which light is carefully excluded. When dry, it is ready for the market. Each vat yields from 36 to 50 lbs. of indigo" (Grace-Calvert).

The same process carried out in the times of the Greeks is thus described by Dioscorides: "Indigo used in dyeing is a purple-colored froth formed at the top of the boiler; this is collected and dried by the manufacturer; that possessing a blue tint and being brittle is esteemed the most."

The identity of the blue coloring matter of woad and that of the Bengal plant was proved by Hellot and by Planer and Trommsdorff at the end of the last century. These latter chemists showed that the blue color of the woad can be sublimed and thus obtained in the pure state; a fact which was first mentioned in the case of indigo by O'Brien, in 1789, in his treatise on calico printing. Indigo thus purified is termed indigotin. It has been analyzed by various chemists, who ascertained that its composition may be most simply expressed by the formula C_8H_5NO.

Indigo is a blue powder, insoluble in water, alkalies, alcohol and most common liquids. In order to employ it as a dyeing agent it must be obtained in a form in which it can be fixed or firmly held on to the fibres of the cloth. This is always effected by virtue of a property possessed by indigo-blue of combining with hydrogen to form a colorless body, soluble in alkalies, known as indigo-white or reduced indigo, of which the simplest formula is C_8H_6NO. This substance rapidly absorbs oxygen from the air and passes into the blue

insoluble indigo which, being held in the fibre of the cloth, imparts to it a permanent blue dye. This reduction to white indigo may be effected in various ways. The old cold vat, or blue-dip vats as they are termed, consist of a mixture of indigo, slaked lime and green vitriol. The latter salt reduces the indigo and the white indigo dissolves in the lime water. This process of indigo dyeing is both expensive and troublesome, owing to loss of indigo and formation of gypsum, so that many plans have been proposed to remedy these evils.

Concerning the origin of indigo in the leaves of the *Indigofera*, various and contradictory views have been held. Some have supposed that blue indigo exists ready formed in the plant, others that white indigo is present which, on exposure to air, is converted into indigo-blue. Schunck has, however, proved beyond doubt that the woad plant (*Isatis tinctoria*), the *Indigofera tinctoria* of India and the Chinese and Japanese indigo plant (*Polygonum tinctorium*) contain neither indigo-blue nor white indigo ready formed. It is now known that by careful treatment the leaves of all these indigo-yielding plants can be shown to contain a colorless principle termed indican, and that this easily decomposes, yielding a sugar-like body and indigo-blue. That white indigo is not present in the leaves is proved by the fact that this compound requires an alkali to be present in order to bring it into solution, whereas the sap of plants is always acid. The decomposition is represented by Schunck as follows:

$$\underset{\text{Indican.}}{C_{26}H_{31}NO_{17}} + 2H_2O = \underset{\text{Indigotin.}}{C_8H_5NO} + 3\underset{\text{Indiglucin.}}{C_6H_{10}O_6}.$$

So readily does this change from indican to indigo take place that bruising the leaf or exposing it to great cold is sufficient to produce a blue stain. Even after mere immersion in cold alcohol or ether, when the chlorophyl has been removed the leaves appear blue, and this has been taken to show the pre-existence of indigo in the plant. But these appearances are deceptive, for Schunck has proved that if boiling alcohol or ether be used, the whole of the color-producing body as well as the chlorophyl is removed, the leaves retaining only a faint yellow tinge, whilst the alcoholic extract contains no indigo-blue, but on adding an acid to this liquid the indican is decomposed and indigo-blue is formed.

Passing now to the more immediate subject of his discourse, the speaker again reminded his hearers that indigo was the second natural

coloring matter which has been artificially prepared; alizarin, the coloring matter of the madder root, being the first. As a rule, the simpler problems of synthetic chemistry are those to which solutions are the soonest found, and these instances form no exception to the rule. The synthetic production of indigo is a more difficult matter than the artificial formation of alizarin, and hence the speaker did not apologize for leading up to the complex through the more simple phenomenon.

When the ingenious Japanese workman, who had never seen a watch, had one given to him in order to make a duplicate, he took the only sensible course open to him, and carefully pulled the watch to pieces, to see how the various parts were connected together. Having once ascertained this, his task was a comparatively easy one, for he then had only to make the separate parts and fit them together, and he thus succeeded so well in imitating the real article that no one could tell the difference. So it is with the chemist; until he knows how the compound is built up, that is, until he has ascertained its constitution, any attempt at synthesis is more like groping in the dark than like shaping the course by well-known landmarks into harbor.

In the case of alizarin it was easy to reduce it to its simplest terms and to show that the backbone of this coloring matter is anthracene, $C_{14}H_{10}$, a hydrocarbon found in coal-tar. This fact being ascertained, the next step was the further process of clothing the hydrocarbon by adding four atoms of oxygen and subtracting the two atoms of hydrogen present in excess, and this was soon successfully accomplished, so that now, as we know, artificial alizarin has excluded the natural coloring matter altogether.

$C_{14}H_{10}$. Anthracene. $C_{14}H_6O_2(OH)_2$. Alizarin.

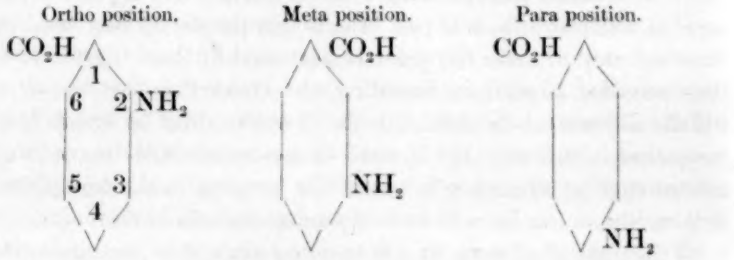
What now was the first step gained in our knowledge concerning the constitution of indigo, of which the simplest formula is C_8H_5NO?

Step No. 1.—This was made so long ago as 1840, when Fritsche proved that aniline, $C_6H_5NH_2$, can be obtained from indigo. The name for this now well-known substance is indeed derived from the Portuguese "anil," a word used to designate the blue color from indigo. This result of Fritsche's is of great importance, as showing that indigo is built up from the well-known benzine ring, C_6H_6, the skeleton of all the aromatic compounds and, moreover, that it contains an amido- group.

STEP No. 2 was also made by Fritsche in the following year, when, by boiling indigo with soda and manganese dioxide, he obtained ortho-amido-benzoic acid or, as he then termed it, anthranilic acid. The following is the reaction which here occurs:

$$\underset{\text{Indigo.}}{C_8H_5NO} + O + 2H_2O = \underset{\text{Ortho amido-benzoic acid.}}{C_7H_5NH_2O_2} + CH_2O_2.*$$

What light does this fact shed upon the constitution of indigo? It shows (1) that one of the eight atoms of carbon in indigo can be readily separated from the rest; (2) that the carboxyl and the amido-group are in neighboring positions in the benzine ring, viz., 1 and 2. For we have three isomeric acids, of the following composition:



STEP No. 3.—The next advance of importance in this somewhat complicated matter is the discovery by Erdmann and Laurent independently, that indigo on oxidation yields a crystalline body which, however, possesses no coloring power, to which they gave the name of isatin.

$$\underset{\text{Indigo.}}{C_8H_5NO} + O = \underset{\text{Isatin.}}{C_8H_5NO_2}.$$

STEP No. 4.—The reverse of this action, viz., the reduction of isatin to indigo, was accomplished by Baeyer and Emmerling in 1870 and 1878, by acting with phosphorus pentachloride on isatin and by the reducing action of ammonium sulphide on the chloride thus formed.

Understanding now something of the structure and of the relationships of the body which we wish to build up, let us see how this edifice has, in fact, been reared. Three processes have been successfully employed for carrying out this object. But of these three, only one is of practical importance. A synthetic process may yield the wished-for result, but the labor incurred may be too great and the losses

* Böttinger, *Deut. Chem. Ges.*, 1877, i, 269.

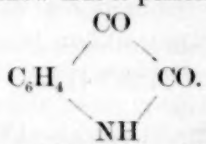
during the campaign may be too severe to render it possible to repeat the operation with advantage on a large scale. Just as it costs, at the usual rate of wages, more than twenty shillings to wash a sovereign's worth of gold out of the Rhine sands, so that this employment is only carried on when all other trades fail.

For the sake of completeness let us, however, consider all three processes, although Nos. 1 and 2 are at present beyond the pale of practical schemes.

These three processes have certain points in common. (1) They all proceed from some compound containing the benzine nucleus. (2) They all start from compounds containing a nitrogen atom. (3) They all commence with an ortho- compound.

They differ from one another, inasmuch as process No. 1 starts from a compound containing 7 atoms of carbon (instead of 8), and to this, therefore, one more atom must be added; process No. 2, on the other hand, starts from a body which contains exactly the right number (8) of carbon atoms; whilst No. 3 commences with a compound in which 9 atoms of carbon are contained and from which, therefore, 1 atom has to be abstracted before indigo can be reached.

Process No. 1 (Kekulé—Claissen and Shadwell).—So long ago as 1869, Kekulé predicted the constitution of isatin and gave to it the formula which we now know that it possesses, viz.:



Following up this view, Claissen und Shadwell, two of Kekulé's pupils, succeeded in preparing isatin and, therefore, indigo from ortho-nitro-benzoic acid.

The following are the steps in the ascent:

1. Ortho-nitro-benzoic acid acted on by phosphorus pentachloride yields the chloride, $C_6H_4(NO_2)COCl$.

2. This latter heated with silver cyanide yields the nitril, $C_6H_4(NO_2)CO.CN$.

3. On heating this with caustic potash it yields ortho-nitro-phenyl-glyoxylic acid, $C_6H_4(NH_2)CO.CO_2H$.

4. This is converted by nascent hydrogen into the amido- compound, $C_6H_4(NH_2)CO.CO_2H$.

5. And this loses water and yields isatin, $C_6H_4NH.CO.CO$.

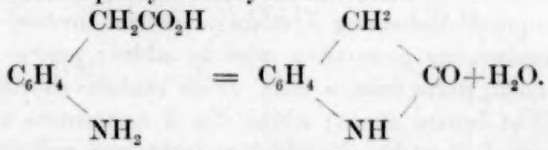
(Q. E. D.)

The reasons why this process will not work on a large scale are patent to all those who have had even bowing acquaintance with such unpleasant and costly bodies as phosphorus pentachloride or cyanogen.

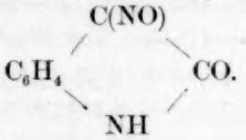
Process No. 2.—Baeyer's (1878) synthesis from ortho-nitro-phenyl-acetic acid.

This acid can be obtained synthetically from toluol, and it is first converted into the amido- acid and which, like several ortho- compounds, loses water and is converted into a body called oxindol, from which isatin and, therefore, indigo can be obtained. The precise steps to be followed are:

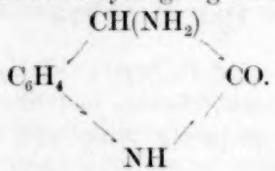
1. Ortho-amido-phenyl-acetic yields oxindol:



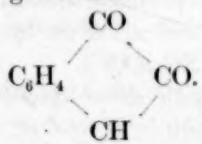
2. This on treatment with nitrous acid yields nitros-oxindol:



3. This, again, with nascent hydrogen gives amidoxindol:



4. Which on oxidation gives isatin:



(Q. E. D.)

This process, the feasibility of which had also been foreseen by Kekulé, is, however, not available as a practical scheme for various reasons.

Process No. 3.—This may be called the manufacturing process and was also proposed by Baeyer. It starts from cinnamic acid, a sub-

stance contained in gum benzoin, balsam of Peru and some few other aromatic bodies. These sources are, however, far too expensive to render this acid thus obtained available for manufacturing purposes. But Bertagnini, in 1856, had obtained cinnamic acid artificially from oil of bitter almonds, and other processes for the same purpose have since been carried out. Of these, that most likely to be widely adopted is the following practical modification, by Dr. Caro, of Mr. Perkin's beautiful synthesis of cinnamic acid:

1. $C_6H_5CH_3 + 4Cl = C_6H_5CHCl_2 + 2HCl.$
   Toluene. Benzylene Dichloride.

2. $C_6H_5CHCl_2 + 2CH_3.CO.O.Na =$
   Benzylene Dichloride. Sodium Acetate.

$$C_6H_5CH{=}{=}CH.CO.OH. + 2NaCl.$$
Cinnamic Acid.

But why did Baeyer select this 9-carbon acid from which to prepare indigo? For this he had several reasons. In the first place, it had long been known that all indigo compounds when heated with zinc dust yield indol, C_8H_7N, a body which stands, therefore, to indigo in the same relation as anthracen to alizarin, and Baeyer and Emmerling had, so long ago as 1869, prepared this indol from ortho-nitro-cinnamic acid, thus: $C_8H_6(NO_2)CO_2H = C_8H_7N + O_2 + CO_2$.

Secondly, the ortho-nitro-cinnamic acid required (for we must remember that indigo is an ortho- compound and also contains nitrogen) can be readily prepared, and this itself again can be obtained on a large scale. Thirdly, this acid readily parts with one atom of carbon and thus renders possible its conversion into 8-carbon indigo.

The next steps in the process are (3) the formation of ortho-nitro-cinnamic acid, (4) the conversion of this into its dibromide, (5) the separation from this of the two molecules of hydrobromic acid, giving rise to ortho-nitro-phenyl-propiolic acid, and (6) lastly, the conversion of this latter into indigo by heating its alkaline solution with grape sugar, xanthate of soda or other reducing agent. These reactions are thus represented:

3. $C_6H_5CH{=}{=}CHCOOH \quad C_6H_4(NO_2)CH{=}{=}CH.COOH.$
   Cinnamic Acid yields Ortho-nitro-cinnamic Acid.

In this process the para- acid is also obtained and, as this is useless for the manufacture of indigo, it has to be removed. This is effected by converting the acids into their ethyl-ethers which, possessing dif-

ferent degrees of solubility, can be readily separated from one another.

4. This is next converted into the dibromide,

$$C_6H_4(NO_2)CHBr.CHBrCOOH.$$

5. And by careful treatment with caustic soda this yields ortho-nitro-phenyl-propiolic acid, thus:

$$C_6H_4(NO_2)CHBrCHBrCOOH + 2NaOH =$$
$$= C_6H_4(NO_2)C_2.COOH + 2NaBr + 2H_2O.$$

6. $n[C_6H_4(NO_2)C_2.COOH + H_2 = C_8H_5NO + CO_2 + H_2O]$.

Ortho-nitro-phenyl-propiolic Acid. Indigotin.

(Q. E. D.)

The last of these reactions is in reality not so simple as the equation indicates. For only about 40 per cent. of indigo is obtained, whereas according to theory 68 per cent. should result. Indeed, although, as we have seen, indigo can be prepared by these three methods, chemists are as yet in doubt as to its molecular weight, the probability being that the molecule of indigo contains twice 16 atoms of carbon, or has the formula $4(C_8H_5NO)$ or $C_{32}H_{20}N_4O_4$. Still it must be remembered that, according to Sommaruga, the vapor-density of indigo is 9·45, a number corresponding to the simpler formula $C_{16}H_{10}N_2O_2$.

The artificial production of indigo may even now be said to be within reasonable distance of commercial success, for the ortho-nitro-phenyl-propiolic acid, the colorless substance which on treatment with a reducing agent yields indigo-blue, is already in the hands of the Manchester calico printers and is furnished by the Baden Company for alkali and aniline colors at the price of 6s. per lb. for a paste containing 25 per cent. of the dry acid.

With regard to the nature of the competition between the artificial and the natural coloring matters, it is necessary to say a few words. In the first place, the present price at which the manufacturers are able to sell their propiolic acid is 50s. per kilo. But 100 parts of this can only yield, according to theory, 68·58 parts of indigo-blue, so that the price of the artificial (being 73s. per kilo.) is more than twice that of the pure natural color. Hence, competition with the natural dye-stuff is not to be thought of until the makers can reduce the price of dry propiolic acid to 20s. per kilo., and also obtain a theoretical yield from their acid. This may, or it may not, be some day accomplished, but at present it will not pay to produce indigo from nitro-phenyl-propiolic acid. Nevertheless, a large field lies open in the immediate future for turning Baeyer's discovery to practical account. It is well

known that a great loss of coloring matter occurs in all the processes now in use for either dyeing or printing with indigo. It has already been stated that a large percentage of indigo is lost in the "cold vats" in the sediment. Another portion is washed off and wasted after the numerous dippings; whilst, in order to produce a pattern, much indigo must be destroyed before it has entered into the fibre of the cloth. Moreover, the back of the piece is uselessly loaded with color. In the processes of printing with indigo the losses are as great or even greater and, in addition, such considerable difficulties are met with that only a few firms (Potter, Grafton in Manchester and Schlieper in Elberfeld) have been successful in this process. But a still more important fact remains, that no printing process exists in which indigo can be in combination with other colors in the ordinary way, or without requiring some special mode of fixing after printing. Hence it is clear that the weak points of natural indigo lie in the absence of any good process for utilizing the whole of its coloring matter and in the impossibility, or, at any rate, great difficulty, of employing it in the ordinary madder styles of calico printing. Such were the reasons which induced the patentees to believe that, although the artificial dye cannot be made at a price to compete with natural indigo for use in the ordinary dye-beck, it can even now be very largely used for styles to which the ordinary dyestuff is inapplicable.

To begin with, Baeyer employed (Patent 1177) grape-sugar as a reducing agent. The reduction in this case does not take place in the cold, and even on long standing only small traces of indigo are formed, but if heated to 70° or upwards the change takes place. Unfortunately this production of indigo-blue is rapidly followed by its reduction to indigo-white and it is somewhat difficult in practice to stop the reaction at the right moment. But "necessity is the mother of invention," and Dr. Caro, of Mannheim, to whom the speaker is greatly indebted for much of the above information, found that sodium xanthate is free from many of the objections inherent to the glucose reduction process, inasmuch as the reaction then goes on in the cold. Moreover, he finds that the red isomeride of indigo-blue, indirubin, which possesses a splendid red color, also occurring in natural indigo, but whose tinctorial power is less than that of the blue, is produced in less quantity in this case than when glucose is employed. On this cloth, alumina and iron mordants may be printed and this afterwards dyed in alizarin, etc., or this coloring matter may also be printed on

the cloth and the color fixed by moderate steaming without damage to the indigo-blue. This process is now in actual use by printers both in England and on the Continent; so that, thanks especially to the talent and energy of Dr. Caro, Baeyer's discovery has been practically applied within the short space of twelve months of its conception. Operations on a manufacturing scale have been successfully carried on in the Baden Soda and Aniline Works at Ludwigshafen for the last two months and the directors see no reason why they should not be able to supply any demand, however great, which may be made for ortho-nitro-phenyl-propiolic acid.

The proper way of looking at this question at present is, therefore, to consider ortho-nitro-phenyl-propiolic acid and indigo as two distinct products not comparable with each other, inasmuch as the one can be put to uses for which the other is unfitted and there is surely scope enough for both. Still, looking at the improvements which will every day be made in the manufacturing details, he must be a bold man who would assert the impossibility of competition with indigo in all its applications. For we must remember that we are only at the beginning of these researches in the indigo field. Baeyer and other workers will not stay their hands, and possibly other coloring matters of equal intensity and of equal stability to indigo may be obtained from other as yet unknown or unrecognized sources, and it is not improbable that these may turn out to be more formidable competitors in the race with natural indigo than ortho-nitro-phenyl-propiolic acid.

Looking at this question of the possible competition of artificial with the natural indigo from another point of view, it must, on the other hand be borne in mind that the present mode of manufacturing indigo from the plant is extremely rude and imperfect, and that by an improved and more careful carrying out of the process great saving in coloring matter may be effected, so that it may prove possible to produce a purer article at a lower price and thus to counterbalance the production of the artificial material.

The following are the directions issued by the patentees to calico printers for using the new color:

Printing with Artificial Indigo.

No. 1.—*On Unprepared Cloth.*

Standard.—Take 4 lbs. propiolic acid paste (equal to 1 lb. dry acid)

and 1 lb. borax, finely powdered; mix well. The mixture first becomes fluid, and at last turns stiff. Then add 3 quarts white starch thickening (wheat starch), mix well and strain.

Printing Color.—Take the above standard and dissolve in it immediately before printing 1½ lbs. xanthate of soda, stir well, and ready for use.

For lighter shades, reduce the above printing color with the following: In 1 gallon white starch paste dissolve 1 lb. xanthate of soda.

Directions for Use.—Print and dry as usual. The pieces ought not to be placed in immediate contact with drying cylinders, or otherwise be subjected to heat above 100°C. The indigo-blue is best developed by allowing the printed goods to remain in a dry atmosphere and at an ordinary temperature for about 48 hours. Damp air ought to be excluded as much as possible until the color is fully developed; then the pieces may be passed through the ageing machine, or steamed at low pressure if such treatment should be required for fixing any other color or mordant printed along with the indigo-blue.

After the blue is ready formed the pieces are first thoroughly washed in the washing-machine, and *then boiled* in the clean water, or better, in a weak solution of hyposulphite of soda (1 lb. to 10 gallons), *and at a full boil* for half an hour, in order to volatilize the smell, which would otherwise adhere to the goods.

Clean in a soap-bath at a temperature not above 40°C.; wash, dry and finish.

Observations.—Wheat starch gives the best results in the color, then follows gum tragacanth. The color is considerably reduced by using gum senegal, dark British gum or calcined farina as thickening materials.

So far borax has answered best as an alkaline solvent of propiolic acid; it may, however, be replaced in the above standard by acetate of soda (from 1 to 1½ lbs.) or by 6 ozs. pearlash or soda. Any excess of caustic potash or soda destroys propiolic acid.

The above standard keeps unchanged for any length of time. It is likewise not sensibly altered by a small amount of xanthate of soda, but when mixed with its full proportion of xanthate, as in the above printing color, it gradually loses strength after several hours.

The xanthate ought, therefore, to be mixed with the standard immediately before printing, and any color remaining unused may then be saved by mixing with the same a large proportion of starch paste.

Propiolic acid may be printed along with aniline-black, catechu brown and drabs, and with alumina and iron mordants for madder colors.

After the indigo-blue is fully developed, the mordants are fixed in the ordinary manner, dyed with alizarin, padded with Turkey-red oil, steamed, and otherwise treated as usual.

Indigo-blue, whether natural or artificial, suffers by prolonged steaming at high pressure. For this reason only such steam colors can be associated with propiolic acid as may be fixed by short steaming at low pressure.

No. 2.—*On Prepared Cloth (for Full Shades.)*

Dissolve 2 lbs. of xanthate of soda in 1 gallon of cold water. Pad the goods with the above, dry, print with standard, and after printing follow the above treatment. The pieces may also be first printed with xanthate and then covered with standard. Alumina and iron mordants for madder colors may be likewise printed on cloth thus prepared, or printed with xanthate of soda.

The potential importance, from a purely commercial point of view, of the manufacture may be judged of by reference to the following statistics, showing that the annual value of the world's growth of indigo is no less than four millions sterling.

Estimated Yearly Average of the Production of Indigo in the World, taken from a Total Crop for a Period of Ten Years.

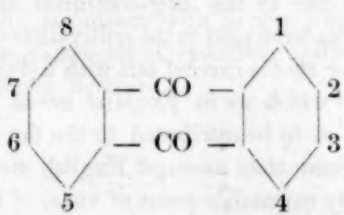
	Pounds weight.	Pounds ster.
Bengal, Tirhoot, Benares and N. W. India,	8,000,000	2,000,000
Madras and Kurpah, . . .	2,200,000	400,000
Manilla, Java, Bombay, etc., . .	.....	500,000
Central America, . . .	2,250,000	600,000
China and elsewhere consumed in the country,	.....	say 500,000
		4,000,000

How far the artificial will drive out the natural coloring matter from the market cannot, as has been said, be foreseen. It is interesting, as the only instance of the kind on record, to cast a glance at the history of the production of the first of the artificial vegetable coloring matters—alizarin. In this case the increase in the quantity produced since its discovery in 1869 has been enormous; such, indeed, that the artificial color has now entirely superseded the natural one to the almost complete annihilation of the growth of madder root. It appears that

whilst, for the ten years immediately preceding 1869, the average value of the annual imports of madder root was over 1,000,000 sterling, the imports of the same material during last year (1880) amounted only to £24,000. The whole difference being made up by the introduction of artificial alizarin. In 1868 no less a quantity than 60,000 tons of madder root were sent into the market, this containing 600,000 kilos. of pure natural alizarin. But, in ten years later, a quantity of artificial alizarin, more than equal to the above amount, was sent out from the various chemical factories; so that in ten years the artificial production had overtaken the natural growth, and the 300,000 or 400,000 acres of land, which had hitherto been used for the growth of madder, can henceforward be better employed in growing corn or other articles of food. According to returns, for which the speaker had to thank Mr. Perkin, the estimated growth of madder in the world previous to 1869 was 90,000 tons, of the average value of £45 per ton, representing a total of £4,050,000.

Last year (1880) the estimated production of the artificial coloring matter was 14,000 tons, but this contains only 10 per cent. of pure alizarin. Reckoning one ton of the artificial coloring matter as equal to 9 tons of madder, the whole artificial product is equivalent to 126,000 tons of madder. The present value of these 14,000 tons of alizarin paste, at £122 per ton, is £1,568,000; that of 126,000 tons of madder, at £45, is £5,670,000, or a saving is effected by the use of alizarin of considerably over 4,000,000 sterling. In other words, we get our alizarin dyeing done now for less than one-third of the price which we had to pay to have it done with madder.

Our knowledge concerning the chemistry of alizarin has also proportionately increased since the above date. For whilst at that time only one distinct body having the above composition was known, we are now acquainted with no less than nine of the ten dioxy-anthraquinones whose existence is theoretically possible, according as the positions of the two semi-molecules of hydroxyl are changed.



Of the nine known dioxy-anthraquinones only one, viz., alizarin, or that in which the hydroxyls are contained in the position 1, 2, is actually used as a coloring agent. Then again, three trioxy-anthraquinones, $C_4H_5O_2(OH)_3$, are known. One of these is contained in madder root, and has long been known as purpurin. The other trioxy-anthraquinones can be artificially prepared. One, termed anthrapurpurin, is an important coloring matter, especially valuable to Turkey-red dyers as giving a full or fiery red. The other, called flavo-purpurin, gives an orange dye with alumina mordants. All these various coloring matters can now be artificially produced, and by mixing these in varying proportions a far greater variety of tints can be obtained than was possible with madder alone, and thus the power of diversifying the color at will is placed in the hands of the dyer and calico printer.

It is quite possible that in an analogous way a variety of shades of blue may be ultimately obtained from substituted indigoes, and thus our catalogue of coal-tar colors may be still further increased.

To Englishmen it is a somewhat mortifying reflection that whilst the raw materials from which all these coal-tar colors are made are produced in our country, the finished and valuable colors are nearly all manufactured in Germany. The crude and inexpensive materials are, therefore, exported by us abroad to be converted into colors having many hundred times the value, and these expensive colors have again to be bought by English dyers and calico printers for use in our staple industries. The total annual value of manufactured coal-tar colors amounts to about three and a half millions; and as England herself, though furnishing all the raw material, makes only a small fraction of this quantity, but uses a large fraction, it is clear that she loses the profit on the manufacture. The causes of this fact which we must acknowledge, viz., that Germany has driven England out of the field in this important branch of chemical manufacture, are probably various. In the first place, there is no doubt that much of the German success is due to the long-continued attention which their numerous universities have paid to the cultivation of organic chemistry as a pure science, for this is carried out with a degree of completeness and to an extent to which we in England are as yet strangers. Secondly, much again is to be attributed to the far more general recognition amongst German than amongst English men of business of the value, from a merely mercantile point of view, of high scientific train-

ing. In proof of this it may be mentioned that each of two of the largest German color works employs no less a number than from 25 to 30 highly educated scientific chemists, at salaries varying from £250 to £500 or £600 per annum. A third cause, which doubtless exerts a great influence in this matter, is the English law of patents. This, in the special case of coloring matters at least, offers no protection to English patentees against foreign infringement, for when these colors are once on the goods they cannot be identified. Foreign infringers can thus lower the price so that only the patentee, if skillful, can compete against them, and no English licencees of the patent can exist. This may, to some extent, account for the reluctance which English capitalists feel in embarking in the manufacture of artificial coloring matters. That England possesses, both in the scientific and in the practical direction, ability equal to the occasion, none can doubt. But be that as it may, the whole honor of the discovery of artificial indigo belongs to Germany and to the distinguished chemist Professor Adolf Baeyer, whilst towards the solution of the difficult problem of its economic manufacture, the first successful steps have been taken by Dr. Caro and the Baden Aniline and Soda Works of Mannheim.

Influence of Varying Pressure upon Pendulums.—M. Saint-Loup finds, as a first result of his experiments upon the influence of atmospheric pressure upon the duration of pendulum oscillations, that there is an increase of about $\frac{1}{13}$ of a second per day for a fall of ten millimetres in the barometer. He does not attach much importance to this figure, regarding it merely as an indication of the order of magnitude of the disturbances; but it seems to show the importance of a correction for pressure in all calculations of exact time. Tresca states that when the conference was held, under the direction of Le Verrier, for the construction of three Parisian regulators of precision, one of the constructors, M. Redier, had fitted to the pendulum a metallic barometer, with an arm which was displaced so as to compensate the variations of retarding influence in the atmospheric pressure.—*Comptes Rendus.* C.

UNIVERSAL ENERGY OF LIGHT.*

By PLINY EARLE CHASE, LL.D.
Professor of Philosophy in Haverford College.

Force is generally regarded as a function of mass and velocity. The greatest known velocities which can be produced by central forces are wave velocities. The greatest known wave velocity which appears to be universally diffused is the velocity of light.

Let v_λ = velocity of light; v_o = circular orbital velocity at Sun's surface = $\sqrt{g_o r_0}$; v_3 = Earth's mean orbital velocity; v_r = velocity of Sun's equatorial rotation; u_3 = potential velocity of water at 0°C. = $\sqrt{2g \times 100 \times 1389{\cdot}6 \text{ ft.}}$; u_4 = potential velocity of water at its maximum density; u_s = potential velocity of water evaporation = $\sqrt{2g \times 536{\cdot}37 \times 1389{\cdot}6 \text{ ft.}}$; m_0, m_3, m_5, m_6 = masses of Sun, Earth, Jupiter, Saturn; h_o = Earth's semiaxis major; h_2 = height of mean oscillatory projection due to the combining energy of H_2O; t_a = time of acquiring circular orbital velocity at Laplace's limit of synchronous rotation and revolution = time of rotation $\div 2\pi$; t_n = time of acquiring "nascent" or dissociative velocity at nucleal surface = $\frac{1}{2}$ time of rotation = πt_a; $\varkappa$ = Weber's electro-chemical unit; μ = electro-magnetic unit; φ_o = total magnetic force; φ_3 = terrestrial magnetic force; t_o = present value of t_n at Sun's surface; g_o = gravitating acceleration at Sun's surface.

The simplicity of the relations of the universal velocity (v_λ) to other physical velocities is shown in the following equations:

1. $$\frac{v_\lambda}{u_3} = \frac{h_o}{h_2} = \frac{m_o}{m_3} = \left(\frac{t_n}{t_a}\right)^2 \cdot \sqrt{\frac{\varphi_o}{\varphi^3}}$$

2. $$\frac{v_\lambda}{v_o} = \frac{v_o}{u_4} \cdot \sqrt{2} = \frac{t_n}{t_a} \cdot \frac{v_o}{v_r}$$

3. $$\frac{v_\lambda}{g_o} = t_o$$

* Abstract of a paper read before the American Association for the Advancement of Science, August, 1881.

4. $\frac{v_\lambda}{v_3} = \frac{\sqrt{m_\circ m_5}}{m_3} = \frac{m_\circ}{m_3}\frac{t_\circ}{t_n}\sqrt{\frac{\mu}{\varkappa}}$

5. $\frac{v_\lambda}{u_s} = \frac{3^4 m_\circ}{2 m_6} = \frac{5\times 3^3 m_\circ}{m_5}$

The velocity of solar atmospheric rotation, at the secular mean centre of gravity of the solar system, is also equivalent to u_s.

The law of conservation of areas, in an expanding or contracting nucleus, requires that $g_\circ$ should vary inversely as $t_\circ$. Equation 3 should, therefore, hold good for all stages of solar existence, past, present and future.

The values which satisfy the above equations are: $m_\circ = 328470\, m_3$; $h_\circ = 92476500$ miles; $v_\lambda = 185760$ miles; $v_3 = 18{\cdot}412$ miles; $u_3 = 2986$ ft.; $u_\circ = 6916{\cdot}2$ ft.

The following table shows the accordance between theoretical and observed values.

	Theoretical.	Observed.
Boiling point of water, .	99·18°	100°
Combining heat of H_2O., .	69319	67616 to 69584*
$\varphi_\circ$, . . .	140·65	140 lb. per sq. in.
Maximum density of water,	4·19°	3·33° to 4·85°
v_3, . . .	18·31	18·41
Latent heat of steam, .	536·374°	536·385°†
$\varkappa \div \mu$, . .	107·38	106·67

The velocity of light is also a factor of electromotive energy. Weber and Kohlrausch demonstrated this fact by measuring quantity of electricity; Thomson and Maxwell by measuring electromotive force; Ayrton and Perry by measuring electrostatic capacity.

Perhaps the most interesting of the above indications is the past, present and future equivalence of Sun's "nascent" velocity to the velocity of light, the sum of the cyclical reactions of solar superficial gravitation against the actions of external gravitation, during each half-rotation, being *equivalent to the velocity of light.*

* The mean of six estimates, cited by Neumann, is 68886.

† This is the mean of four estimates, viz.: Favre and Silbermann, 535·77; Andrews, 535·90; Regnault, 536·67; Tyndall, 537·20.

Algerian Wine.—The portions of Algeria which are near the shores of the Mediterranean are very favorable to the growth of grapes. The colonists are rapidly removing the dwarf palm trees and the underbrush, in order to plant vineyards. The change is going on with wonderful rapidity. The vines bear fruit after three years, and they are at present subject to no injury except from the sirocco and white frost in some localities. The income after five or six years reaches a mean value of 4000 francs per hectare (324 dollars per acre). —*Les Mondes.* C.

Disturbances of Telephonic Transmission.—M. A. Gaiffe has noticed electrical currents in bars of iron which are set in vibration by shocks. He attributes them to induction. According to Ampère's theory he thinks that a vibrating magnet should produce currents analogous to the extra currents which would arise in a vibrating solenoid.—*Les Mondes.*

[Mousson studied the influence of vibrations on the conductibility of wires in 1858. In 1864 Chase showed that the daily and annual variations of the magnetic needle may be imitated by exposing them to mechanical vibrations similar to those which are produced by thermal conditions. C.]

Compensation of Geodetic Triangles.—E. Adan discusses the triangulation of Belgium, in which the network is so united as to furnish satisfactory bases for calculations relative to the dimensions of the globe. Two bases were measured nearly on the same parallel, one at Lommel, the other near Ostende. They were united by thirty-nine triangles having the Antwerp coast near the middle. Sixteen triangles separate this coast from the Lommel base and twenty-three from that of Ostende. The probable error of the combined measurements was less than $\frac{1}{4400}$. This approximation would seem sufficiently close, but by means of intermediate compensations the probable error was reduced to less than $\frac{1}{278\,00}$ of one per cent. It is rare that in calculations of so complicated a character a comparison can be readily made between two coordinate methods, and the result in this case is such as to recommend the system of compensations which was undertaken. —*Bull. de l'Acad. Belg.* C.

Felling Trees with Dynamite.—M. Pinsot, the forester of the Bois de Boulogne, has experimented with dynamite upon several trees which it was thought desirable to remove. He finds that dynamite can be used very advantageously, both in point of economy and rapidity of execution, for uprooting and dividing stumps of trees, but it is not applicable to felling trees which are to be used as timber.—*Les Mondes.* C.

Improvement in Compasses. — Miller and Pfaundler have devised a method for reading the indications of the compass with great accuracy. The magnetic needle carries near its ends two thin discs of aluminum; upon each of the discs a fine line is drawn so as to indicate the plane in which the pivot of the needle stands. A microscope and vernier are attached, together with a small disc of paper or mica, which stands perpendicularly upon the needle so as to bring it more speedily to rest by means of the resistance of the air.—*Dingler's Journal.* C.

Absolute Measure of Currents by Electrolysis. — After having introduced a system of absolute measures for electric magnitudes, Weber determined the electro-chemical equivalent of water, or the weight of water decomposed in a second by a unit of electromagnetic intensity. His valuation of the equivalent was ·009376 of a milligramme. The experiment has been repeated by various observers, but the results present variations of about 2 per cent. Mascart has repeated the investigation with numerous new precautions to eliminate possible causes of error, and he finds the equivalent ·009373 of a milligramme.—*Comptes Rendus.* C.

Influence of Sun Spots upon Temperature.—J. Liznar has compared the observations at St. Petersburg, Caterinenburg, Barnaul, Prague, Brünn, Vienna, Kremsmünster, Trieste, Rome, Calcutta, Batavia and Hobarttown, and finds marked evidence of a relation between the oscillations of daily temperature and of sun spots. The minima of daily oscillation correspond very closely with the maxima of sun spots; the maximum of oscillation precedes the minimum of sun spots by about two years. In the annual temperature the maximum of spots corresponds to the maximum of oscillation and the minimum of spots to the minimum of oscillation.—*Les Mondes.* C.

Upper Atmospheric Currents.—Count D'Epiennes has conducted meteorological researches which were based only upon observation, without bias by any theoretical ideas, and which lead him to the following conclusions: 1. The air rises from zones of low pressure towards the upper regions and then flows towards the centres of high pressure. 2. As the current proceeds in the upper regions it tends to form a depression. The culmination and deviations which tempests undergo in their march are governed by upper currents directed towards their centre.—*Ciel et Terre.* C.

New Heating Apparatus.—The great calorific capacity of water has hitherto rendered it the most usual reservoir of utilized heat. There are, however, some fusible bodies which allow the storing of a much greater quantity of heat in the same volume without increasing the temperature of the vessels which contain them. Acetate of soda, for example, when melted, contains about four times as much available heat as water. M. A. Ancelin has accordingly experimented with it in suitable boxes for warming cars and carriages. His experiments upon the French railroads have been so satisfactory that his system seems likely to be adopted by many of the roads in Portugal, Italy, Spain and England.—*Comptes Rendus.* C.

Franklin Institute.

HALL OF THE INSTITUTE, Sept. 21st, 1881.

The stated meeting was called to order at 8 o'clock P.M., the President, Mr. William P. Tatham, in the chair.

There were present 38 members and 3 visitors.

The minutes of the last meeting were read and approved.

Mr. Tatham then said: "Before proceeding to any business, I feel it proper to bring before the meeting the mournful circumstances under which we are assembled. The President of the United States has just died after a long struggle against the death wound received some months ago. I feel there is not a citizen who participated in the election which made General Garfield President who does not feel his loss as a personal sorrow. I feel sure we all regard it as a public calamity. The opening months of his administration were so full of

fruit that we all indulged in the anticipation of a bright future, and whatever may be the course of events hereafter, the picture of his bright administration will be without a shadow. He has left us a great example. To the young, an example of what may be accomplished by diligence, study and a well-directed ambition; to men, an example of the power of justice, moderation and candor; and to all an example of cool courage in the face of death, and of patient resignation to the will of the Almighty."

Mr. Samuel Sartain moved that, in view of our great national bereavement, the Institute now adjourn, which was carried.

ISAAC NORRIS, M.D., *Secretary.*

LIST OF BOOKS ADDED TO THE LIBRARY DURING JULY, AUGUST AND SEPTEMBER, 1881.

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Agriculture, Maine Board of. Twenty-fourth Annual Report of Secretary. Augusta, 1880. Presented by the Board.

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Astronomical and Meteorological Observations for 1876. In 2 parts. Washington, 1880. Presented by U.S. Naval Observatory.

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Engineer. Vols. 1 and 2. London, 1856.

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Geological Exploration of the Fortieth Parallel. Vol. 7. Washington, 1880. Presented by Chief of Engineers, U. S. A.

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Internal Revenue—Report of Commissioner for 1880. Washington. Presented by the Commissioner.

Journal of the Telegraph. Vol. 10. New York, 1877. Presented by Isaac Norris, M.D.

Keller. Berechnung und Construction der Triebwerke. Munich, 1881. Presented by the Author.

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Manchester Steam Users' Association. Reports for 1879.
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Merchant Vessels of the United States. Lists for 1870 to 1873 and 1878 to 1880. Washington.
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Meteorological Committee of the Royal Society. London. International. Report of Meeting at Berne, 1880.
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Metropolitan Museum of Art. Tenth and Eleventh Annual Report of the Trustees. New York, 1880–81. Presented by the Trustees.

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Navy of United States, Register of Officers in. Washington, 1881.
Navy of United States, Reports of Secretary, 1878–80.
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Pipes and Tubes. 1867—1876.
Specifications and Drawings. Vols. 52–54 of 1879 and Vols. 1–20 of 1880. Presented by the Commissioners of Patents.

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Rankine, W. J. M. Scientific Papers. London, 1881.

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